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HYDROLOGIC CHARACTERIZATION OF NOSR 1

March 1982

Work Performed Under Contract No. AC01-78RA32012

TRW
Energy Engineering Division
McLean, Virginia

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

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Naval Oil Shale Reserves Management Support and Systems Engineering Project

March 1982

Performed under Contract No. DE-AC01-78RA32012
for the U.S. Department of Energy

TRW ENERGY ENGINEERING DIVISION
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TABLE OF CONTENTS

	Page
1. EXECUTIVE SUMMARY	1-1
2. INTRODUCTION	2-1
2.1 PROGRAM BACKGROUND	2-1
3. PHYSICAL ENVIRONMENT OF NOSR 1	3-1
3.1 INTRODUCTION	3-1
3.2 PHYSIOGRAPHY	3-1
3.3 CLIMATE	3-3
3.4 VEGETATION	3-3
3.5 GEOLOGY	3-4
3.5.1 Stratigraphy	3-4
3.5.1.1 Wasatch Formation	3-4
3.5.1.2 Green River Formation	3-7
3.5.1.2.1 Douglas Creek Member	3-9
3.5.1.2.2 Garden Gulch Member	3-10
3.5.1.2.3 Anvil Points Member	3-10
3.5.1.2.4 Parachute Creek Member	3-11
3.5.1.3 Uinta Formation	3-17
3.5.1.4 Quaternary Alluvium	3-17
3.5.2 Geologic Structure	3-17
4. CHARACTERISTICS OF THE HYDROLOGIC SYSTEM ON NOSR 1	4-1
4.1 INTRODUCTION	4-1
4.2 INFLOW INTO THE NOSR 1 HYDROLOGIC SYSTEM	4-2
4.2.1 Precipitation	4-2
4.2.1.1 Precipitation Gage Network Data	4-2
4.2.1.2 Snow Course Network Data	4-4
4.2.1.3 Estimated Total Annual Precipitation on NOSR 1	4-13
4.3 OUTFLOW FROM THE NOSR 1 HYDROLOGIC SYSTEM	4-13
4.3.1 Surface Water	4-13
4.3.1.1 Drainage Description and Gage Network	4-13

TABLE OF CONTENTS (CONTINUED)

			Page
		4.3.1.1.1 East Fork Parachute Creek	4-15
		4.3.1.1.2 East Middle Fork Parachute Creek	4-18
		4.3.1.1.3 Ben Good Creek	4-19
	4.3.1.2	Annual Surface Water Runoff Characteristics	4-19
		4.3.1.2.1 East Fork Parachute Creek	4-19
		4.3.1.2.2 East Middle Fork Parachute Creek	4-21
		4.3.1.2.3 Ben Good Creek	4-22
		4.3.1.2.4 Estimated Total Annual NOSR 1 Surface Water Runoff	4-24
		4.3.1.2.5 Comparison of Precipitation and Discharge for Water Years 1979 and 1980	4-24
	4.3.1.3	Rainfall-Runoff Relationships	4-25
	4.3.1.4	Estimated Baseflow on NOSR 1	4-28
	4.3.1.5	Surface Water Quality	4-31
4.3.2	Groundwater		4-36
	4.3.2.1	Background	4-36
	4.3.2.2	Field Procedures and Analytical Methods	4-37
	4.3.2.3	Aquifer Parameters	4-40
		4.3.2.3.1 Zone 1	4-41
		4.3.2.3.2 Zone 2	4-41
		4.3.2.3.3 Zone 3	4-46
		4.3.2.3.4 Zone 4	4-49
	4.3.2.4	Geohydrology	4-49
		4.3.2.4.1 Recharge Characteristics	4-49
		4.3.2.4.2 Discharge Characteristics	4-52
		4.3.2.4.3 Potentiometric Surfaces	4-56
	4.3.2.5	Groundwater Quality	4-63
		4.3.2.5.1 Zone 1	4-65
		4.3.2.5.2 Zone 2	4-68
		4.3.2.5.3 Zone 3	4-71

TABLE OF CONTENTS (CONTINUED)

Page

4.3.2.5.4 Zone 4 4-74
4.3.2.5.5 Vertical Variation 4-77
4.3.2.5.6 Quality of Spring Water 4-79

4.3.3 Evapotranspiration 4-84

4.3.3.1 Estimated Evapotranspiration from the NOSR 1 Hydrologic System 4-84

4.4 NOSR 1 WATER BALANCE 4-89
4.5 ESTIMATED WATER IN STORAGE ON NOSR 1 4-91

5. SUMMARY OF FINDINGS 5-1

6. GLOSSARY 6-1

7. BIBLIOGRAPHY 7-1

LIST OF FIGURES

Figure		Page
3-1	Naval Oil Shale Reserves No. 1 and 3	3-2
3-2	Regional Structure, Piceance Creek Basin and Vicinity	3-5
3-3	Generalized Stratigraphic Section of the Piceance Creek Basin	3-6
3-4	Extent of the Green River Formation in Colorado, Utah, and Wyoming	3-8
3-5	Terminology of the Parachute Creek Member of the Green River Formation	3-12
3-6	NOSR 1 Structure Contour - Top of the Big Three	3-14
3-7	NOSR 1 Structure Contour - Top of the Mahogany Bed	3-16
4-1	Index Map, NOSR 1 Precipitation Gages	4-3
4-2	Comparative Plot - NOSR 1 Precipitation Records, Water Year 1977	4-5
4-3	Comparative Plot - NOSR 1 Precipitation Records, Water Year 1978	4-6
4-4	Comparative Plot - NOSR 1 Precipitation Records, Water Year 1979	4-7
4-5	Comparative Plot - NOSR 1 Precipitation Records, Water Year 1980	4-8
4-6	Index Map, NOSR 1 Snow Reconnaissance Network	4-11
4-7	Index Map, NOSR 1 Surface Water Gages	4-16
4-8	Annual Hydrographs - East Fork Parachute Creek Gages, Water Years 1977 through 1980	4-23
4-9	Annual Hydrographs - East Middle Fork Parachute Creek Gages, Water Years 1977 through 1980	4-23
4-10	Annual Hydrographs - Ben Good Creek Gage, Water Years 1977 through 1980	4-23
4-11	Storm Hydrographs - July 2-3, 1980, East Fork Parachute Creek Gages	4-26

LIST OF FIGURES (CONTINUED)

Figure		Page
4-12	Storm Hydrographs - July 2-3, 1980, Northwater Creek and East Middle Fork Parachute Creek Gages	4-27
4-13	East Fork Parachute Creek - Water Year 1979 Annual Hydrograph Showing Estimated Range of Baseflow	4-30
4-14	Piper Diagram Showing Water Quality Surface Water at Gages on NOSR 1	4-33
4-15	Graphs Showing the Chemical Character at Three Surface Water Gaging Stations on NOSR 1	4-35
4-16	NOSR 1 Zone 1 Recovery Transmissivity and Hydraulic Conductivity Values	4-43
4-17	NOSR 1 Zone 2 Recovery Transmissivity and Hydraulic Conductivity Values	4-45
4-18	NOSR 1 Zone 3 Recovery Transmissivity and Hydraulic Conductivity Values	4-48
4-19	NOSR 1 Zone 4 Recovery Transmissivity and Hydraulic Conductivity Values	4-51
4-20	Isolated Stream Reaches on NOSR 1 Which Show a Decrease in Discharge in the Downstream Direction	4-53
4-21	Index Map, DOE/TRW Spring Reconnaissance Locations	4-54
4-22	Representative NOSR 1 Spring Temperature and Specific Conductivity Values	4-55
4-23	NOSR 1 Zone Water Levels, February 1982	4-58
4-24	NOSR 1 Zone 1, Potentiometric Surface Map	4-59
4-25	NOSR 1 Zone 2, Potentiometric Surface Map	4-60
4-26	NOSR 1 Zone 3, Potentiometric Surface Map	4-61
4-27	NOSR 1 Zone 4, Potentiometric Surface Map	4-62
4-28	Piper Diagram of Chemical Analyses from NOSR 1 Zone 1 . . .	4-66
4-29	Piper Diagram of Chemical Analyses from NOSR 1 Zone 2 . . .	4-69
4-30	Piper Diagram of Chemical Analyses from NOSR 1 Zone 3 . . .	4-72

LIST OF FIGURES (CONTINUED)

Figure		Page
4-31	Piper Diagram of Chemical Analyses from NOSR 1 Zone 4 . . .	4-75
4-32	Water Quality Stiff Patterns for Wells 15/16 and 17 Showing Increase in Dissolved Solids and Change in Ionic Character of Groundwater with Increasing Depth . . .	4-78
4-33	Piper Diagram of Chemical Analyses from NOSR 1 Springs . .	4-81
4-34	Piper Diagram of Chemical Analyses from Three Selected Springs on NOSR 1	4-83
4-35	Stiff Diagrams for Chemical Analyses of Springs Sampled in 1981	4-85

LIST OF TABLES

Table		Page
3-1	Relative Stratigraphic Position of Important Subunits of the Parachute Creek Member on NOSR 1	3-13
4-1	NOSR 1 Precipitation Gages	4-4
4-2	Summary of USGS JQS Snow Course Data	4-9
4-3	Comparison of JQS Snow-Course Water-Content Data to JQS Precipitation Gage Records	4-9
4-4	Summary of NOSR 1 Snow Reconnaissance Network Maximum Values Winter 1980-1981	4-12
4-5	Estimated Total NOSR 1 Snow-Pack Water-Content, Winter 1980-1981	4-12
4-6	Estimated Total Spring/Summer/Fall Precipitation on NOSR 1 for Water Years 1977 through 1980	4-14
4-7	Adjusted Snow-Pack Water-Content Data for the USGS JQS Snow Course for the Winters of 1978-1979 and 1979-1980	4-15
4-8	Estimated Total Annual Precipitation on NOSR 1 for Water Years 1979 and 1980	4-15
4-9	NOSR 1 Surface Water Gages	4-17
4-10	Summary of Discharge Data - East Fork Parachute Creek Near Anvil Points	4-20
4-11	Summary of Discharge Data - East Fork Parachute Creek Near Rulison	4-20
4-12	Summary of Discharge Data - Northwater Creek Near Anvil Points	4-21
4-13	Summary of Discharge Data - East Middle Fork Parachute Creek Near Rio Blanco	4-21
4-14	Summary of Discharge Data - Ben Good Creek Near Rulison	4-22
4-15	Estimated Total Annual Surface Water Runoff from NOSR 1	4-24

LIST OF TABLES (CONTINUED)

Table		Page
4-16	Comparison of NOSR 1 Estimated Total Annual Precipitation to Estimated Total Annual Discharge	4-24
4-17	Estimated NOSR 1 Annual Baseflow for Water Years 1979 and 1980	4-29
4-18	Yearly Average Value of Major Constituents of Chemical Analyses of Surface Water Samples from NOSR 1 During Water Year 1980	4-32
4-19	NOSR 1, Summary of Aquifer Tests for Zone 1	4-42
4-20	NOSR 1, Summary of Aquifer Tests for Zone 2	4-44
4-21	NOSR 1, Summary of Aquifer Tests for Zone 3	4-47
4-22	NOSR 1, Summary of Aquifer Tests for Zone 4	4-50
4-23	Summary of Specific Conductivity Values for NOSR 1 Springs	4-52
4-24	Gas Analyses of Samples Obtained from NOSR 1 Monitor Wells	4-64
4-25	Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 1	4-67
4-26	Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 2	4-70
4-27	Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 3	4-73
4-28	Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 4	4-76
4-29	Summary of Analytical Results for Major Ions and Selected Parameters for Spring Samples Collected on NOSR 1	4-80

LIST OF TABLES (CONTINUED)

Table		Page
4-30	Summary of Analytical Results for Major Ions and Selected Parameters for Three Selected NOSR 1 Springs . . .	4-82
4-31	Summary of Elevation Zone Areas on the NOSR 1 Watershed	4-86
4-32	Estimated Distribution of Vegetation Types by Elevation Zone on NOSR 1	4-86
4-33	Estimated Evapotranspiration on NOSR 1	4-88
4-34	Comparison of NOSR 1 Estimated Total Annual Precipitation to Estimated Total Annual Discharge and Estimated Total Annual Evapotranspiration	4-87
4-35	Estimated NOSR 1 Water Balance for Water Years 1979 and 1980	4-90

LIST OF PLATES

Plate	
1	Cross Section Trending Northwest-Southeast Across NOSR 1 and 3
2	Cross Section Trending East-West Across the Northern Part of NOSR 1 and 3
3	Cross Section Trending East-West Across the Center of NOSR 1 and 3
4	Cross Section Trending East-West Across the Southern Part of NOSR 1 and 3

1. EXECUTIVE SUMMARY

This Hydrologic Characterization report for Naval Oil Shale Reserve No. 1 (NOSR 1) summarizes and analyzes information obtained during the multi-year predevelopment program conducted by TRW, Inc. for the U.S. Department of Energy. The compilation and analyses of this data define the baseline hydrologic conditions and provide important hydrologic information for input into development planning.

To characterize the hydrologic system on NOSR 1, basic data have been collected on precipitation, surface water, and groundwater. The analyses of these data has provided:

- An estimated water balance for NOSR 1
- Baseline definition of water quality for both surface and groundwater on NOSR 1
- Calculation of aquifer parameters for the four water-bearing zones on NOSR 1
- An estimate of water in storage on NOSR 1

Precipitation data was collected at three precipitation gages and from an extensive snow reconnaissance network. Data on surface water quantity and quality was collected at five gaging sites and from over 80 springs. Groundwater aquifer test data and water samples obtained at 10 core holes were used to define the hydraulic and chemical characteristics of each of the four identified water-bearing zones. All basic data is published separately in the NOSR 1 Hydrology Data Book (TRW, March 1982). This report summarizes that data and provides an integrated picture of the hydrologic system on NOSR 1.

NOSR 1 contains the headwater areas of all watersheds that contribute to surface water discharge from the Reserve. Therefore the only inflow into the NOSR 1 hydrologic system is contributed by precipitation. Precipitation gage records have provided a good estimate for non-winter precipitation but have proven unreliable during the winter snow accumulation period. To supplement the gage records, a snow reconnaissance network was established to record snow accumulation by elevation zone for a variety of slope aspects and cover conditions. Snow water content data is available beginning in Water Year 1979 (i.e., October 1978). For Water Years 1979 and 1980, total annual precipitation is estimated to be 24.4 and 25.2 inches, respectively.

Surface water discharge leaving NOSR 1 has been monitored by the U.S. Geological Survey since Water Year 1976. Total annual discharge has ranged from a low of 529.9 acre-feet in Water Year 1977, to a high of 18,296 acre-feet in Water Year 1979. For Water Years 1979 and 1980, total annual surface water discharge in area-inches was 7.37 (18,296 acre-feet) and 6.96 (17,269 acre-feet), respectively. A comparison of these figures to the estimated total annual precipitation of the same water years shows that between 25 and 30 percent of total annual precipitation leaves NOSR 1 as surface water runoff. A further breakdown of surface water runoff into direct snowmelt runoff and baseflow indicates that for these water years, between 8 and 15 percent of total surface water runoff is baseflow (0.59 to 1.07 area-inches or 1,482 to 2,652 acre-feet).

Overall quality of surface water on NOSR 1 is good and meets the U.S. Environmental Protection Agency standards for drinking water. Sodium adsorption ratios are less than 2, and only a low to medium salinity hazard exists according to U.S. Salinity Laboratory Standards (1954), making this water well suited for irrigation. Total dissolved solids range between from slightly more than 225 mg/l to just under 400 mg/l, with annual station averages from 265 to 350 mg/l. The best quality water exists along East Fork Parachute Creek and the highest dissolved solids concentrations are recorded at the Ben Good Creek gage. This pattern reflects a slight north to northwestward increase in dissolved solids concentration across the reserve.

Evapotranspiration on NOSR 1 is estimated to range up to approximately 19 inches. This estimate was based on a study of an adjacent property (Wymore, 1974), and adjusting values from that study for the vegetation distribution on NOSR 1. An independent evaluation of this factor from water balance calculations for Water Years 1979 and 1980 show estimated evapotranspiration to be 17.03 and 18.24 inches, respectively. This means that 70 to 75 percent of total annual precipitation is lost through evapotranspiration.

The groundwater system on NOSR 1 consists of four principal water-bearing zones. Zone 1 is found in the upper part of the Parachute Creek Member above the Big Three rich zone. This water-bearing zone, with an average thickness of about 170 feet, is generally unconfined, in contrast to the lower zones. Calculated transmissivities range from a high of 449 ft^2/day in Well 22, to a low of 1.2 ft^2/day in Well 15/16. With the exception of Well 22, all calculated transmissivities are very low and fall in the permeability range of siltstone. Aquifer response to the drawdown/recovery tests are characteristic of fractured reservoirs and indicate that this zone is a limited aquifer which could be pumped dry in a short period of time with a large pump. Zone 1 groundwater can be classified as calcium bicarbonate at Well 24, mixed-cation bicarbonate at Wells 17, 18, and 22, and sodium bicarbonate at Wells 15/16, 20, and 26. These water types are generally found in recharge areas in the Piceance Creek basin. The dissolved solids concentration and the specific conductance values for the Zone 1 analyses indicate that all but the sample from Well 20 satisfy federal drinking water standards and that Zone 1 water is safe for agricultural use. In the sample for Well 20, iron is high at 5.8 mg/l, fluoride is elevated at 1.6 mg/l, and specific conductance is 1000 micromhos/cm.

Zone 2, located in the vicinity of the "A" Groove, has an average thickness of 20 feet. Calculated transmissivities for this zone range from 0.9 to 105.9 ft^2/day. Response to testing indicated that this zone is a limited aquifer, with several tests resulting in the complete drawdown of the zone in less than 10 minutes. Water in Zone 2 is either mixed-cation-bicarbonate water or sodium-bicarbonate water. The highest current ratio of dissolved solids is found in Well 15/16 and the lowest in Well 21. Among trace constituents, only fluoride was found in significant concentrations with values ranging from 0.3 mg/l at Well 18, to 3.5 mg/l at Well 15/16. The water in Zone 2 does not exceed drinking water or agricultural use standards at Wells 18 and 21, but Wells 15/16 and 17 have a medium sodium and salinity hazard, and exceed drinking water standards for dissolved solids (Well 15/16), and fluoride (both wells).

Zone 3 is located in the vicinity of the B-groove. This zone has an average thickness of 70 feet and has somewhat higher calculated transmissivities and hydraulic conductivities than those for the other three zones.

Calculated transmissivities range from 10.8 to 529 ft^2/day. Aquifer response to the drawdown/recovery tests are characteristic of limited fractured reservoirs. Water samples from Wells 18, 21, and 24 show mixed-cation-bicarbonate water, and the remaining samples are sodium-bicarbonate water. The concentration of dissolved solids ranges from 290 mg/l at Well 21 to 490 mg/l at Well 20. Fluoride concentration exceeds 1 mg/l for five of the samples, and ranges from 0.2 mg/l at Well 24 to 5 mg/l at Well 26. Zone 3 water quality has the least dissolved solids and the most intermediate water type in the central area of NOSR 1, indicating that recharge to this zone may occur in this region. Zone 3 water has a medium salinity and low sodium hazard at the down-gradient wells. Dissolved solids concentrations meet EPA drinking water standards at all wells, but the fluoride concentration exceeds the EPA Standards at Wells 15/16, 17, 20, and 26.

Zone 4 is found below the base of the R-6 zone. On NOSR 1, this zone has an average thickness of 170 feet. Generally, the calculated values of transmissivity and hydraulic conductivity are low and variable depending on geographic location. Calculated transmissivity ranges from a low of 0.8 ft^2/day at Well 15/16, to a high of 48.5 ft^2/day at Well 17. The response of Zone 4 to the aquifer tests are typical of a fractured reservoir and indicate a limited aquifer. All the groundwater in Zone 4 can be classed as sodium-bicarbonate water. The lowest percentage of sodium and lowest dissolved solids concentration are found at Well 21. All wells, except 20, have elevated levels of fluoride with the maximum found at Well 15/16 (7 mg/l). Most wells have low iron concentrations but 2 mg/l is reported for Well 22. The chloride and sodium concentrations at Well 15/16 are the highest recorded on NOSR 1, indicating the possibility of some evaporite mineral dissolution either on the northern rim of the reserve or in the region immediately north towards Piceance Creek. The high concentration of fluoride and dissolved solids at Well 15/16 also reflects the possibility of increased mineral dissolution. A medium salinity hazard exists for groundwater from all wells and a high salinity hazard exists at Wells 15/16 and 20. The sodium hazard is generally low, but a medium hazard is found at Well 20 and a very high sodium hazard is indicated for Well 15/16. Wells 15/16 and 20 exceed EPA drinking water standards for dissolved solids and all wells, except 22, exceed the fluoride standard.

Since very little groundwater development has taken place on NOSR 1, the groundwater system is essentially in a state of hydrologic equilibrium. This state of equilibrium implies that the rate of discharge from the system, which is approximated by surface water baseflow, is equal to the rate of recharge (deep percolation) with no change in storage. Therefore, the estimated range of baseflow for Water Years 1979 and 1980 approximates the groundwater recharge for these two years. Baseflow for these two years range from 0.59 to 1.07 area-inches (1,482 to 2,652 acre-feet) indicating that less than 5 percent of total annual precipitation enters the groundwater system through deep percolation.

An estimate of water in storage on NOSR 1 has been calculated for a fracture porosity range of 1 to 5 percent. Using these porosities and an estimate of the total saturated volume of all four water-bearing zones, NOSR 1 contains between 110,000 and 560,000 acre-feet of groundwater in storage.

2. INTRODUCTION

This Hydrologic Characterization report for Naval Oil Shale Reserve No. 1 (NOSR 1) summarizes the hydrologic information obtained during the multi-year predevelopment program conducted by TRW for the U.S. Department of Energy. This work was performed under contract No. DE-AC01-78RA32012 as part of the effort to establish baseline environmental conditions and to provide important hydrologic information as input into development planning.

The objectives of hydrologic data collection and monitoring activities are as follows:

- Establish baseline data on the quantity and quality of surface and groundwater resources for environmental analyses and for development planning.
- Establish a surface and groundwater monitoring network to allow evaluation of future water quantity and quality changes due to oil shale development activities and to allow assessment of the effectiveness of mitigating measures.
- Design and carry out a groundwater test program to determine the nature of the groundwater system on NOSR 1.

Results from the data and monitoring activities are documented in a companion report "NOSR 1 Hydrology Data Book", dated March 1982. This hydrologic characterization report summarizes characteristics of the baseline hydrologic system on NOSR 1 including inflow (precipitation), outflow (surface, groundwater, and evapotranspiration), and water quality (surface and groundwater).

2.1 PROGRAM BACKGROUND

In September 1976, the U.S. Geological Survey agreed to establish, operate, and maintain a surface water and precipitation monitoring network on NOSR 1 for the U.S. Department of the Navy. Under this agreement, five surface water gages, three precipitation gages, one climate station, and one snow course were established and maintained for a period of three years. In 1979 and again in 1981, this work agreement was extended. The objective of the surface water and precipitation monitoring networks was to establish site-specific baseline precipitation data (inflow), and surface water quantity (outflow) and quality data. These parameters are basic to the understanding of the hydrologic system on NOSR 1.

In the summer and fall of 1977, seven coreholes were drilled on NOSR 1, primarily for resource evaluation. U.S. Geological Survey personnel were on-site during the drilling of these core holes, collecting samples and conducting limited aquifer tests. This aquifer testing was based on a two aquifer zone model for the Piceance Creek basin. This model, based on information available at that time, assumed that the groundwater system consisted of two aquifers separated by the Mahogany zone. In addition to the limited aquifer testing, water samples were collected and analyzed and two coreholes were temporarily completed to allow monitoring of water levels above and below the Mahogany zone. Data from this period of aquifer testing and sampling were reported to the Department of the Navy by the U.S. Geological Survey on April 20, 1978.

In late 1977, jurisdiction over the Naval Oil Shale Reserves was transferred from the Navy to the Department of Energy (DOE). On June 22, 1978, TRW was awarded the contract to provide DOE with management support, and engineering and systems engineering assistance for Phase I of the NOSR predevelopment program. The first activities directed toward meeting the Hydrologic assessment objectives under this contract were incorporated into the late 1978 drilling program. This program was primarily intended to complete the resource assessment on NOSR 1 and required the drilling of three additional coreholes. Hydrologic data was obtained during the drilling of these coreholes, an aquifer testing program was implemented, and five additional coreholes were temporarily completed to allow the water levels above and below the Mahogany zone to be monitored. Data from this testing program was previously reported to the DOE in Drilling/Coring/-Logging, Final Report Naval Oil Shale Reserve No.1, December 15, 1978.

After the 1978 field program, all available corehole and aquifer test data was evaluated. As a result of this detailed evaluation, it was concluded that the groundwater system on NOSR 1 was much more complicated than the two-aquifer model used in previous testing. The conclusion from the data evaluation was that there are four persistent water-bearing zones on NOSR 1. Based on this new interpretation, a field program to test and sample the four water-bearing zones was developed and carried out during the summers of 1980 and 1981. The basic data from this program is reported in the data book mentioned above, and a summary of this data and its interpretation is presented in this report as the NOSR 1 hydrologic characterization.

3. PHYSICAL ENVIRONMENT OF NOSR 1

3.1 INTRODUCTION

The Naval Oil Shale Reserves (NOSR) 1 and 3, occupying an area of approximately 90 square miles, are in Garfield County, Colorado, about five miles northwest of the town of Rifle. NOSR 1 and 3, established in 1916 and 1924, respectively, as potential future sources of oil for the Navy, include: portions of the lowland areas at the base of the Roan Cliffs, the Roan Cliffs themselves, and about 50 square miles of the southeastern portion of the Roan Plateau. NOSR 1 occupies the southern portion of the Roan Plateau and is the area of potential resource development. NOSR 3, situated below the Roan Cliffs, was designated to provide access routes, plant sites, and disposal areas for the potential development work on NOSR 1. Figure 3-1 shows the distribution of NOSR 1 and 3, and their relationship to the surrounding area.

3.2 PHYSIOGRAPHY

Field work in support of this hydrologic investigation was confined to NOSR 1. This area consists of a maturely disected upland, composed of narrow westward trending ridges ranging in elevation from 9,300 to 6,700 feet. These ridges slope toward the west with gradients between 50 and 200 feet per mile. The main intervening valleys, cut by tributaries to Parachute Creek, are generally V-shaped without extensive level upland areas or valley flood plains. Tributaries to the main valleys are short and steep, and flow normal to the main drainages. Overall, NOSR 1 has an intricate, dendritic drainage system.

The southern portion of NOSR 1 is drained by East Fork Parachute Creek which flows westward with a gradient of approximately 200 feet per mile. Downstream of the headwater area, relief from the bottom of East Fork Parachute Creek Valley to the top of the adjacent ridges rapidly reaches 600 feet. Downstream of the falls on East Fork Parachute Creek, this relief increases to more than 1,500 feet.

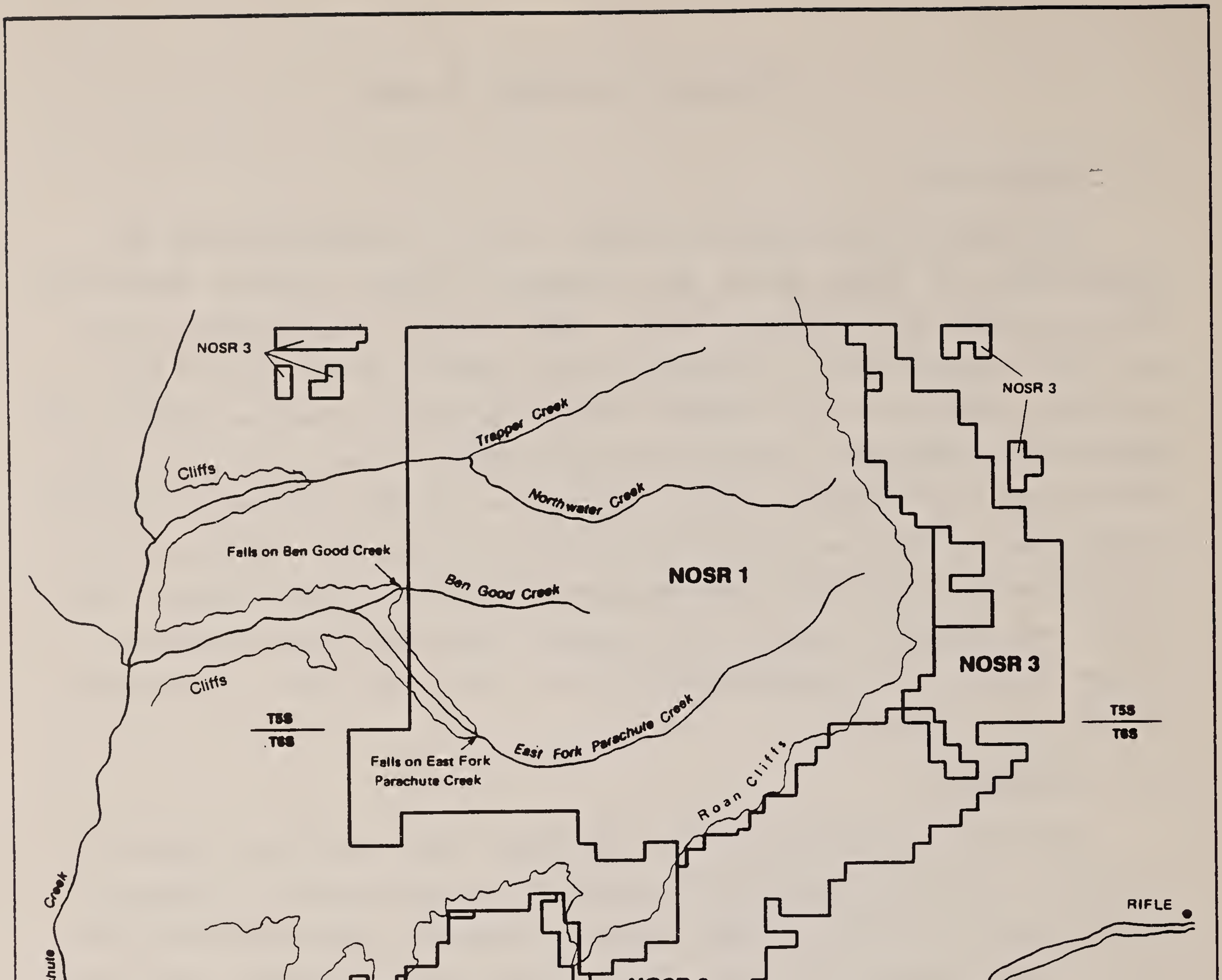


Figure 3-1. Naval Oil Shale Reserves No. 1 and 3

The northern portion of NOSR 1 is drained by East Middle Fork Parachute Creek. This stream flows westward with a gradient of approximately 180 feet per mile and includes two major tributaries - Northwater Creek and Trapper Creek. The headwater areas for these tributaries are relatively broad valleys which gradually narrow downstream. Valley-ridge relief in the upper half of this watershed is about 400 feet. This relative relief increases to 600 feet near the Trapper-Northwater confluence and to more than 800 feet where East Middle Fork Parachute Creek crosses the western boundary of the Reserve.

3.3 CLIMATE

The climate on NOSR 1 can be generally characterized as high altitude, semi-arid. Annual precipitation, as monitored since November of 1976, has ranged from a low of about 12 inches in 1977 to a high of more than 25 inches in Water Year 1980 (October through September). The existing data indicates that in excess of 60 percent of total annual precipitation is in the form of snowfall. Temperature varies from a summer daytime high of about 32°C (90°F), to a winter low of about -28°C (-18°F). Because of the short period of record, these values may not be representative of normal conditions. However, they are the best area-specific values available.

3.4 VEGETATION

Principal vegetation communities on NOSR 1 include upland sagebrush, mixed mountain shrub, and aspen/douglas fir forest (Cook, 1974). Each of these communities are localized according to various physical factors including: elevation, slope, aspect, soil type, and soil moisture. For example, the douglas fir forest community is found only on steep, north-facing slopes. A detailed description of the vegetation on NOSR 1 is included in the Environmental Baseline Characterization of the Naval Oil Shale Reserves (TRW, 1982).

3.5 GEOLOGY

NOSR 1 is located in the southeastern portion of the Piceance Creek basin which contains the world's richest deposit of oil shale. The Piceance basin, a major structural feature of the Colorado Plateau physiographic province, includes an area of approximately 6,700 square miles (Figure 3-2). The Piceance structural basin is bounded on the north by the White River, on the east by the Grand Hogback Monocline and Elk Mountains, on the south by the West Elk Mountains and Uncompaghre Plateau, and on the west by the Douglas Creek arch and the Cathedral Bluffs. The basin axis, which trends generally N 50°W, is approximately coincident with the topographic expression of the basin. Oil shale, found in the Green River Formation, occurs in an area of about 1,600 square miles in the northern portion of the basin, between the Colorado River and the White River.

3.5.1 Stratigraphy

Exposed stratigraphic units on NOSR 1 and 3 include, from oldest to youngest, the Wasatch, Green River and Uinta Formations. All are Eocene in age and record the evolution from a moderate energy fluvial environment (Wasatch Formation) through a widespread low energy lacustrine environment (Green River Formation) into a lake-filling fluvial-lacustrine environment (Uinta Formation). The Uinta Formation is conformable and intertongues with the underlying Green River Formation. On NOSR 1 this formation is found along the tops of the ridges and in the upland areas. On NOSR 1, the Green River Formation outcrops on the upper part of the Roan Cliffs and in the valleys of East Fork and East Middle Fork Parachute Creeks. The Green River Formation is conformable with the underlying Wasatch Formation. The Wasatch Formation crops out on NOSR 3, near the base of the Roan Cliffs. Figure 3-3 is a generalized stratigraphic section of the Piceance Creek basin.

3.5.1.1 Wasatch Formation

The Wasatch Formation is characterized by varicolored shale and clay with locally prominent lenticular sandstone beds. Other minor, local lithologic components include, conglomerate, pebbly sandstone, limestone,

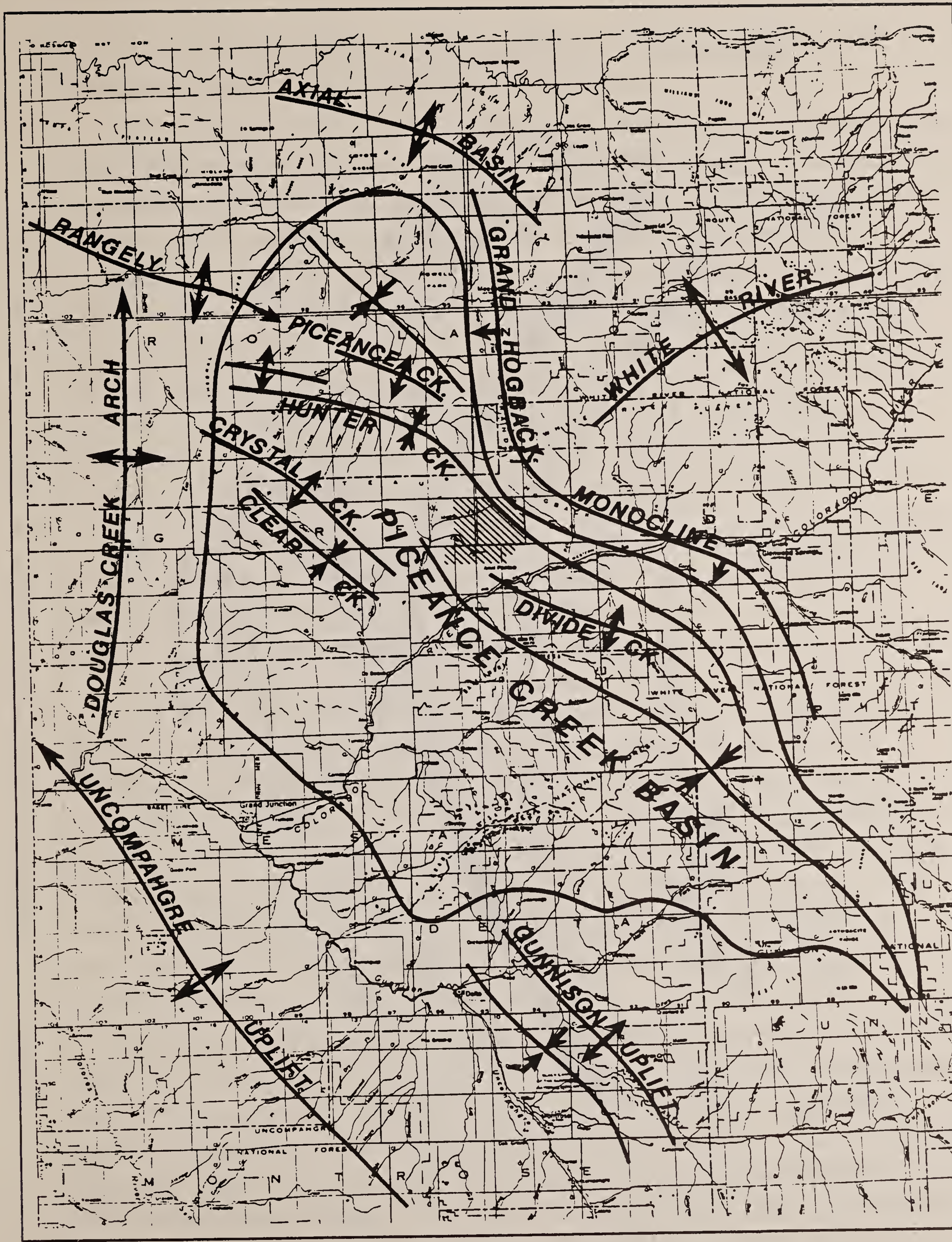


Figure 3-2. Regional Structure, Piceance Creek Basin and Vicinity

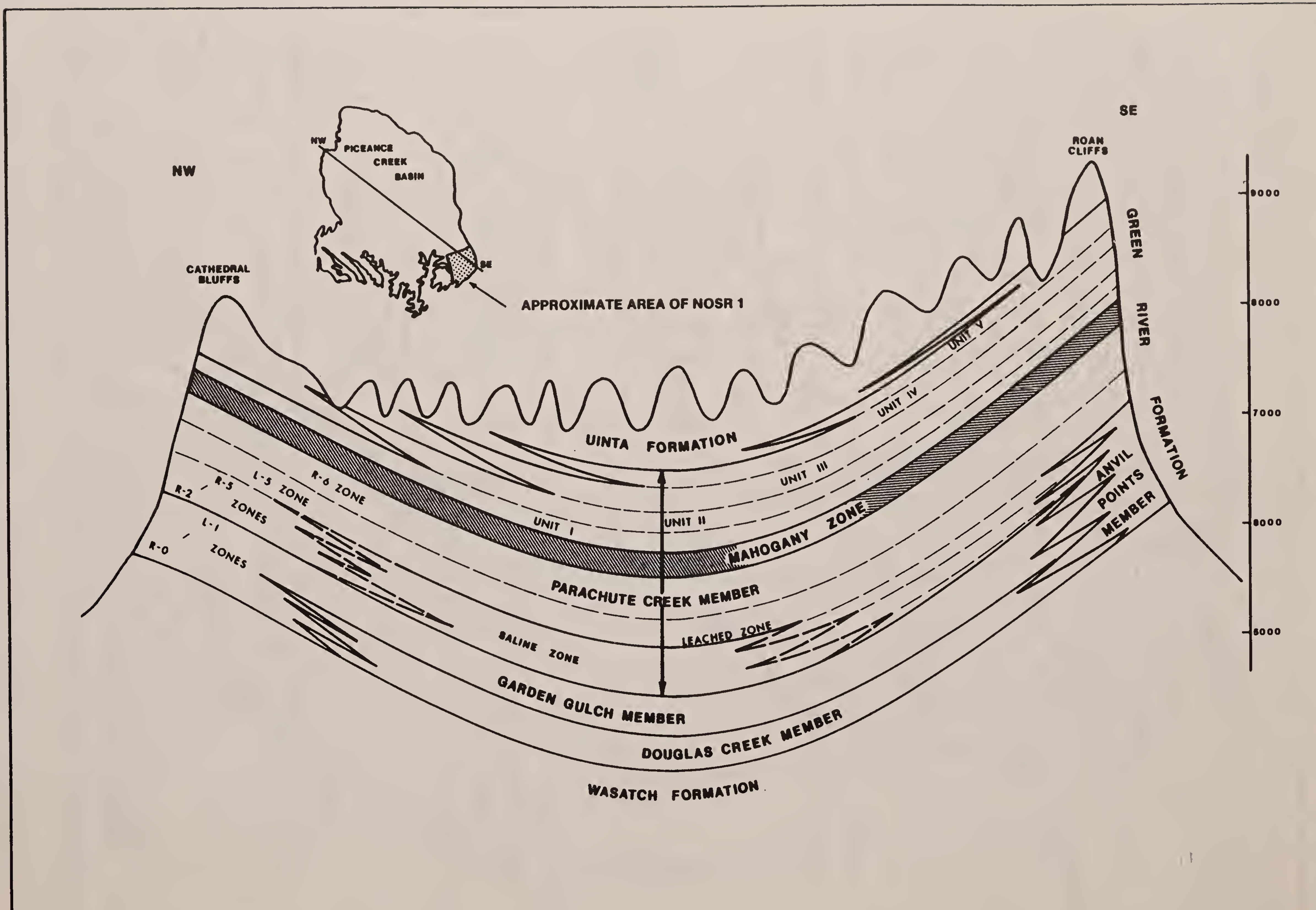


Figure 3-3. Generalized Stratigraphic Section of the Piceance Creek Basin

coal, and black carbonaceous shale (Donnell, 1961). Wasatch Formation lithologies are generally nonresistant to erosion.

East of NOSR 1, this formation forms the lowland area between the Roan Cliffs and the Grand Hogback. South of NOSR 1, the Wasatch Formation forms the lowland area below the Roan Cliffs. The Wasatch Formation, therefore, is found nearly everywhere on NOSR 3 and is not exposed on NOSR 1.

The Wasatch/Green River Formation contact is transitional and not well defined. The principal criterion for placement of this contact has been the color change from the brightly colored, irregularly bedded sedimentary rocks of the Wasatch, to the more regularly bedded, grey marlstone rocks of the overlying Green River Formation. The thickness of the Wasatch Formation varies greatly, generally thinning toward the west. In the vicinity of NOSR 1, the estimated formation thickness is 5,000 feet.

Fossils from the Wasatch Formation in this and adjacent areas indicate an early Eocene age and a dominantly low energy fluvial depositional environment (Donnell, 1961).

3.5.1.2 Green River Formation

The principal lithology of the Green River Formation is a thinly bedded, fine grained argillaceous marlstone, composed primarily of dolomite, clay minerals, feldspar, and quartz, and containing varying quantities of kerogen, a solid hydrocarbon. This formation is remarkable for its regular thin bedding and the lateral continuity of some individual units, and was deposited during Eocene time in large ancient lakes which inundated northwestern Colorado, southwestern Wyoming, and northeastern Utah. Figure 3-4 shows the extent of the Green River Formation in this tri-state area.

On NOSR 1, the Green River Formation crops out along the Roan Cliffs and in the deeper valley areas of the Roan Plateau. In the Piceance Creek basin, the Green River Formation has been subdivided into four members based on lithologic properties and stratigraphic position. From oldest to youngest, these are the Douglas Creek Member, the Garden Gulch Member, and the Parachute Creek Member. The fourth lithologic unit, the Anvil Points Member, is a lateral facies equivalent of the Douglas Creek, Garden Gulch, and lower Parachute Creek Members. Surface and subsurface data indicate

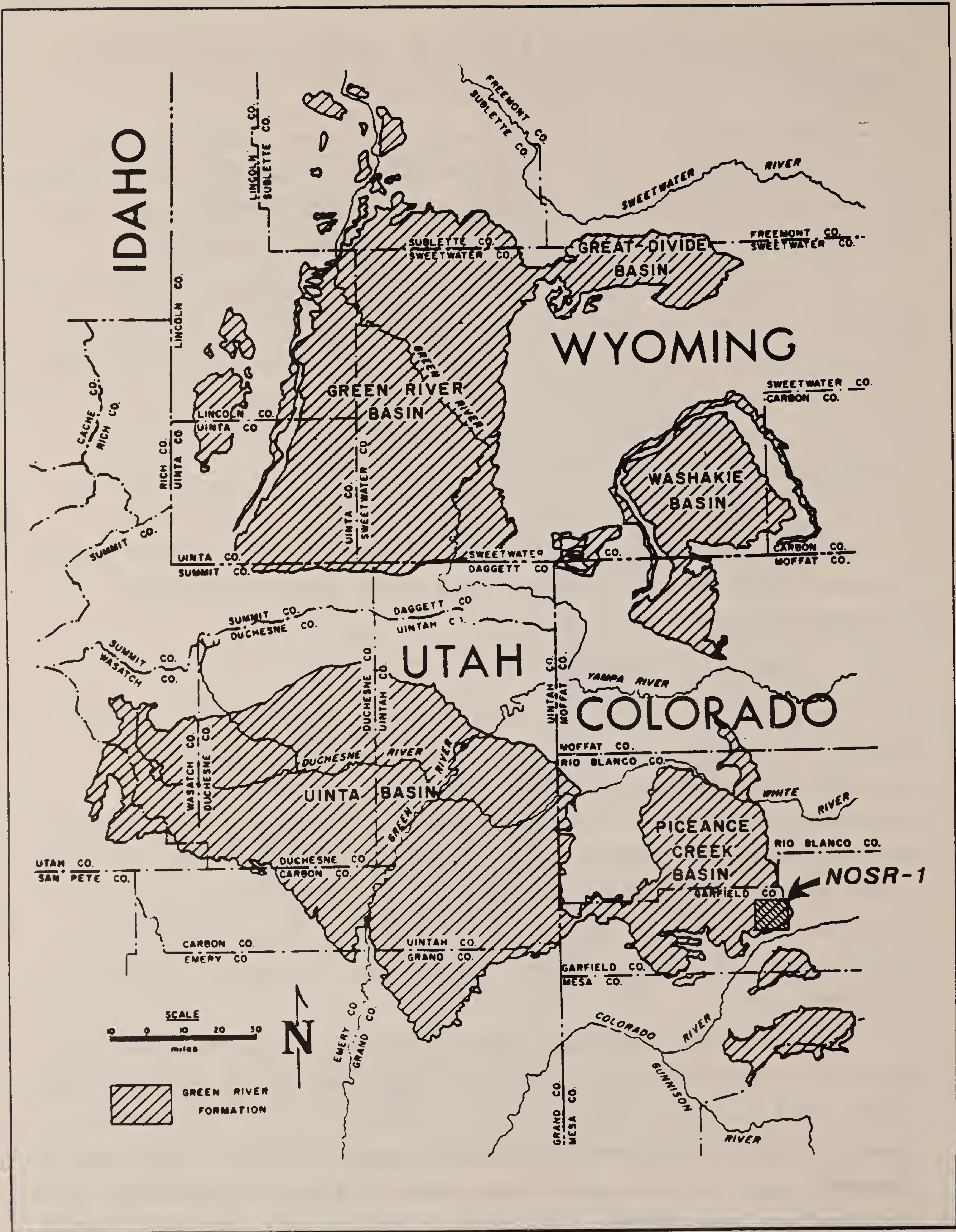


Figure 3-4. Extent of the Green River Formation in Colorado, Utah, and Wyoming

that the total thickness of the Green River Formation within the Piceance Creek basin varies in relationship to the basin depositional axis. At its maximum, this formation exceeds 3,000 feet in thickness.

Within the Green River Formation, all member contacts are gradational and represent transgressive-regressive sequences or changes in the mineralogic composition of the rocks. The Green River/Uinta Formation contact is conformable and is characterized by a complex intertonguing relationship. North of NOSR 1 and 3, six northward extending tongues of Green River Formation have been identified. These include the Yellow Creek, Dry Fork, Thirteen Mile Creek, and Black Sulfur Tongues identified by Duncan and others (1974); the Coughs Creek Tongue identified by O'Sullivan (1975); and the Stewart Gulch Tongue identified by Hail (1977). Field work for this hydrologic investigation noted the presence of tongues on NOSR 1. In addition, a photogeologic evaluation for potential geologic hazards on NOSR 1 (1980) identified multiple tongues of the Green River Formation. However, neither the field work nor the photogeologic evaluation identified and mapped individual tongues. The sedimentary structures, the mineralogy, and the fossil content of the formation, as detailed by Bradley (1931) and Stransfield and others (1951), indicate that this formation was deposited in a Middle Eocene lacustrine environment.

3.5.1.2.1 Douglas Creek Member

The Douglas Creek Member is conformable over and intertongues with sediments of the Wasatch Formation. It consists mainly of light- to medium-brown, cross-bedded, and ripple-marked sandstone, with lesser amounts of limestone and gray shale. The Douglas Creek Member is characterized by its drab colors and resistance to erosion. It represents the beginning transgressive phase of Lake Uinta, and forms a clastic wedge which thins basinward from the Douglas Creek Arch. Its areal extent roughly coincides with the original lake bed of Lake Uinta (Ritzma, 1965; Sladek, 1974; McDonald, 1978).

The type section of the Douglas Creek Member (Bradley, 1931) is located at the head of Trail Creek near Douglas Pass, in T5S, R102W. It crops out around the southern and western sides of the basin, where it is 400 to 800 feet thick. East of Parachute Creek it grades into the Anvil

Points Member, and near the northwestern corner of the basin it grades into the overlying Garden Gulch Member.

3.5.1.2.2 Garden Gulch Member

The Garden Gulch Member is composed mainly of gray to black shales, usually paper-thin and fissile. Lesser amounts of marlstone, thin sandstones, and limestones are also noted. Low-grade oil shales of the Garden Gulch Member yield as much as 15 gallons of oil per ton of rock (Merriam, 1954).

The Garden Gulch Member is 700 feet thick in the valley of Parachute Creek, near the town of Parachute (formerly Grand Valley). Outcrops of this member range in thickness from 100 to 900 feet, extend from Parachute Creek westward and around the edges of the basin to the center of the northern rim. The Garden Gulch Member grades eastward into the Anvil Points Member. On outcrop, it is generally slope forming, in contrast to the overlying and underlying members which are generally cliff-forming. The contact with the underlying Douglas Creek Member is gradational. In the center of the basin, where the Douglas Creek Member is absent, the Garden Gulch Member lies conformably on the Wasatch Formation. The contact with the overlying Parachute Creek Member is also conformable (Merriam, 1954; McDonald, 1972; Tosco, 1979).

3.5.1.2.3 Anvil Points Member

The Anvil Points Member is a heterogeneous clastic unit, 1,500 to 1,900 feet thick. It crops out along the northeast, east, and southeast sides of the basin and pinches out within 8 to 12 miles of its outcrop. The Anvil Points Member is a shoreline facies which interfingers with and grades into the Douglas Creek, Garden Gulch, and lower Parachute Creek Members. This member, named by Donnell (1953), has its type area at Anvil Points, immediately south of NOSR 1. It interfingers with the underlying Wasatch Formation and the overlying Parachute Creek Member. A 40 to 50 foot thick sandstone tongue of the Anvil Points Member, with a slightly greater areal extent, has been referred to as the Piceance Creek Sandstone (Ritzma, 1965).

3.5.1.2.4 Parachute Creek Member

The Parachute Creek Member of the Green River Formation, named by Bradley (1931), contains the thickest and richest deposits of oil shale in the Piceance Creek Basin, and in the world. Because of the magnitude of the resource and the potential for economic recovery, this unit has been studied by numerous workers since Bradley (1931) and subdivided into various informal sub-units. Figure 3-5 summarizes the various stratigraphic nomenclatures found in the literature. Overall, this member is predominantly a thin bedded, ultra-fine grained, light grey to black, dolomitic marlstone which contains varying amounts of organic kerogen. The thin bedded nature of this unit is remarkably persistent, such that individual bed sequences can be traced across the entire basin. Numerous tuff beds, ranging in thickness from less than 1 inch to approximately 5 feet, are found throughout the upper part of this unit. These tuff beds, which are generally analcitized, include several important stratigraphic markers, such as the Wavey bed and the Mahogany marker.

Concentrated primarily in the lower portion of this unit below the Mahogany zone, in the structurally deepest part of the basin, are beds containing thick sequences of the sodium-bicarbonate mineral, nahcolite. Though the nahcolite decreases and disappears moving laterally southward from basin depositional center, thin zones of nahcolite vugs, both filled and empty, are found along bedding planes, in and above the Mahogany zone. Evidence for the one time presence of this mineral throughout the basin includes empty vugs, vugs lined and filled with replacement minerals such as calcite, and collapsed breccia. Vugs and thin solution zones of this type are found over the entire area of NOSR 1. Stratigraphically, they are scattered in the upper part of the unit, but seem to be concentrated in the uppermost 650 feet.

On NOSR 1, important marker beds in the Parachute Creek Member include, from stratigraphically highest to lowest, the Big Three, the Stillwater, the 4-Senators, the Wavey bed, the A-groove, the Mahogany marker, and the Mahogany bed. Table 3-1 summarizes the relative stratigraphic positions of these important sub-units on NOSR 1.

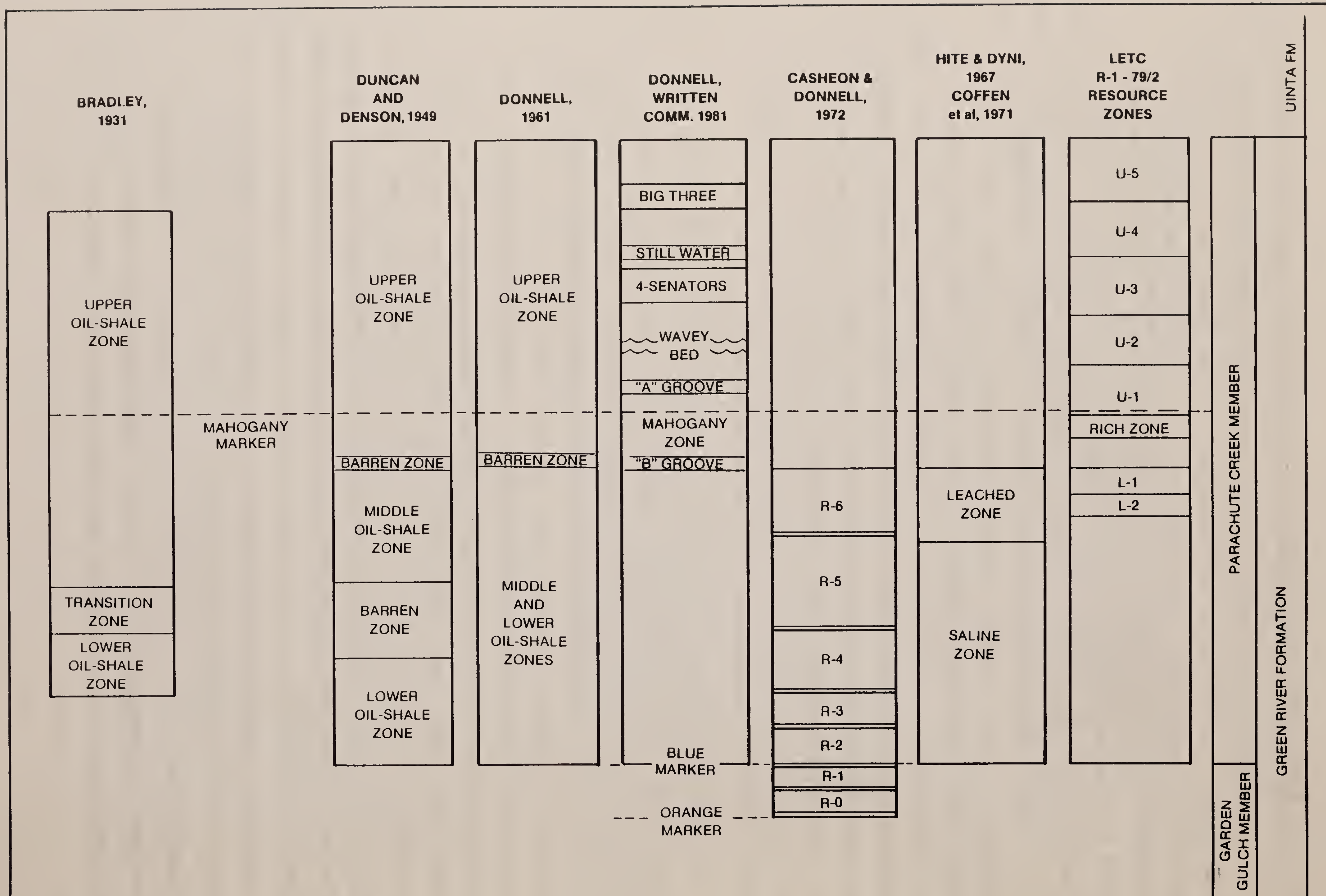


Figure 3-5. Terminology of the Parachute Creek Member of the Green River Formation

Table 3-1. Relative Stratigraphic Position of Important Sub-Units of the Parachute Creek Member on NOSR 1 (Taken from oil yield histograms contained in Resource Assessment Naval Oil Shale Reserve No. 1, TRW, 1979)

Stratigraphic Marker	Depth Range on NOSR 1 to Top of Unit (Feet) below ground surface	Thickness		Distance from Top of Stratigraphic Unit to the Mahogany Bed	
		Range (Feet)	Average (Feet)	Range (Feet)	Average (Feet)
Big Three	0 - 882	20 - 39	30	290 - 366	326
Stillwater	0 - 968	7 - 10	9	235 - 280	256
4-Senators	0 - 1005	25 - 40	33	188 - 243	215
Wavey Bed	0 - 1195	2 - 4	3	92 - 116	103
A-groove	0 - 1195	7 - 16	11	43 - 53	47
Mahogany Marker	0 - 1235	-	0.25	7 - 15	10

The Big Three, located in the upper part of the Parachute Creek Member, is a distinctive series of three thin (1 to 2 feet) rich oil shale beds occurring in a stratigraphic interval of approxmately 30 feet. This marker bed crops out in all the major drainages on NOSR 1. On Trapper Creek, outcrops of the Big Three are found near the headwaters and then dip beneath the surface. It then crops out again approximately 1/2 mile above the confluence with Northwater Creek. On Northwater Creek, outcrops are found near the confluence with Raspberry Creek downstream to the confluence with Trapper Creek. On Ben Good Creek, the Big Three is exposed at the top of the falls. On East Fork Parachute Creek, this marker is exposed above the confluence of JQS and Golden Castle Gulches, and well up into its major tributaries. Figure 3-6 is a structure contour map drawn on top of the Big Three showing the approximate area of outcrop.

The Stillwater is a relatively thin rich zone, located approximately 40 feet below the base of the Big Three. Stillwater zone outcrops are found in appproximately the same area as the Big Three. However, it is not found in the headwater area of Trapper Creek, nor in the Ben Good Creek drainage above the falls.

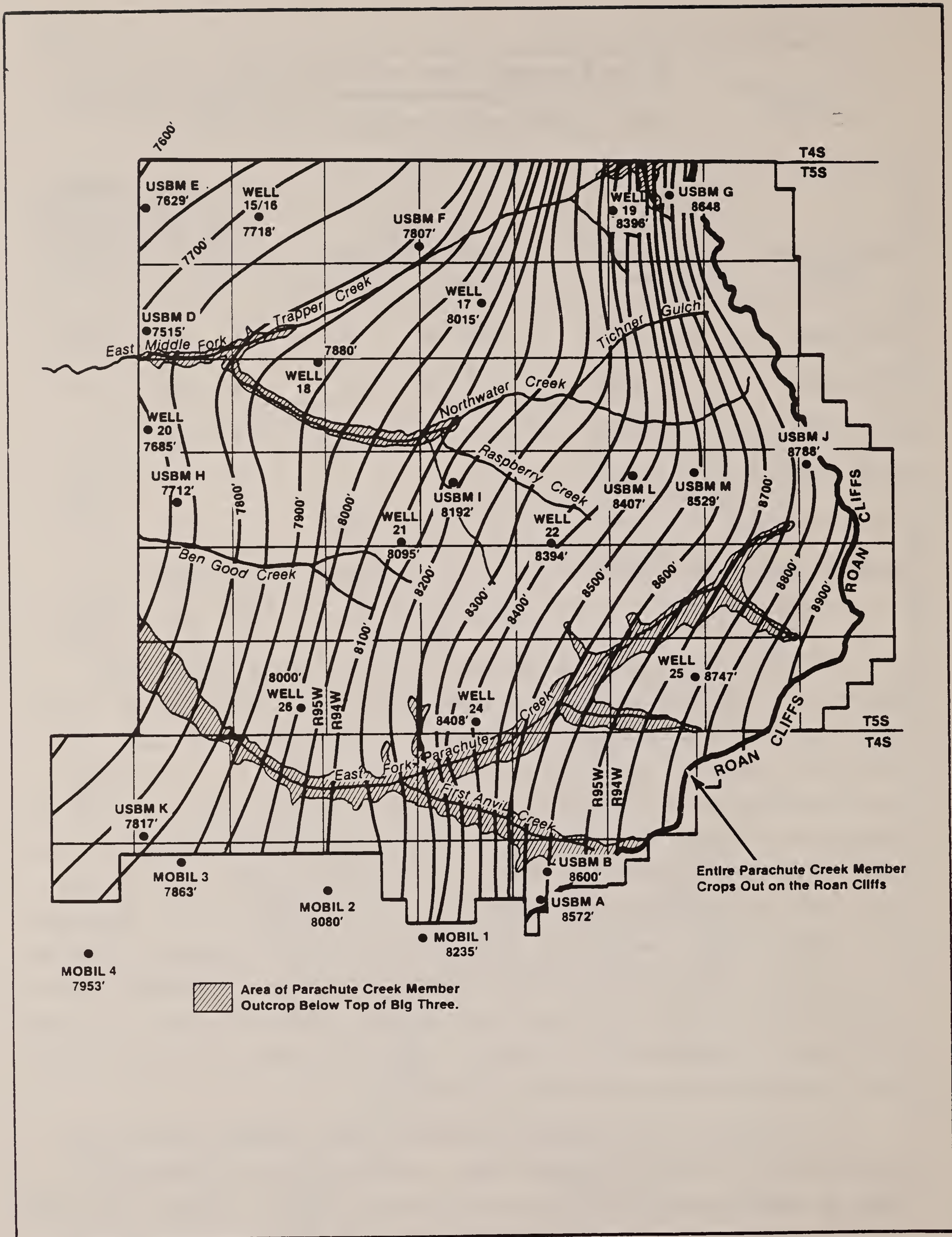


Figure 3-6. NOSR 1 Structure Contour - Top of the Big Three

The 4-Senators zone, located approximately 30 feet below the base of the Stillwater zone, contains four, thin, rich beds in an interval of approximately 30 feet. This zone crops out along East Fork Parachute Creek and its major tributaries. The upstream limit of 4-Senators zone outcrop is above the confluence of JQS Gulch and Golden Castle Gulch. This unit also outcrops along East Middle Fork Parachute Creek, below the Trapper-Northwater Creek confluence.

The Wavey bed is a distinctive tuff bed which ranges in thickness from 2 to 4 feet on NOSR 1. In this marker bed, the tuffaceous materials are intimately mixed with irregular stringers of marlstone. The Wavey bed is located approximately 80 feet below the base of the 4-Senators zone and 90 feet above the Mahogany zone. The Wavey bed, while generally non-resistant to weathering, can be found on outcrop along East Fork Parachute Creek below the confluence of JQS and Golden Castle Gulches, and along East Middle Fork Parachute Creek from the surface water gauge upstream approximately 1/4 mile.

The A-groove is a distinctive interval of lean marlstone and ranges from 7 to 16 feet in thickness on NOSR 1. On outcrop, this interval is non-resistant to weathering and is generally covered with talus. However, when exposed on a cliff face, where the talus is removed by gravity, the A-groove can be identified as a re-entrant interval. Though difficult to recognize on outcrop because of talus, the A-groove can be found along East Fork Parachute Creek downstream from First Water Gulch.

The Mahogany marker is an analcitized tuff bed ranging in thickness from 3 to 5 inches. On NOSR 1, it is located from 7 to 15 feet above the top of the Mahogany Bed which is the richest bed in the Mahogany zone. On NOSR 1, both the Mahogany marker and the Mahogany bed outcrop along an isolated 3.5 mile reach of East Fork Parachute Creek. The outcrop is at, or just above, stream level and extends approximately from the confluence with Second Water Gulch downstream to the confluence with Sheep Trail Hollow. Figure 3-7 is a structure contour map drawn on top of the Mahogany bed showing the approximate area of outcrop.

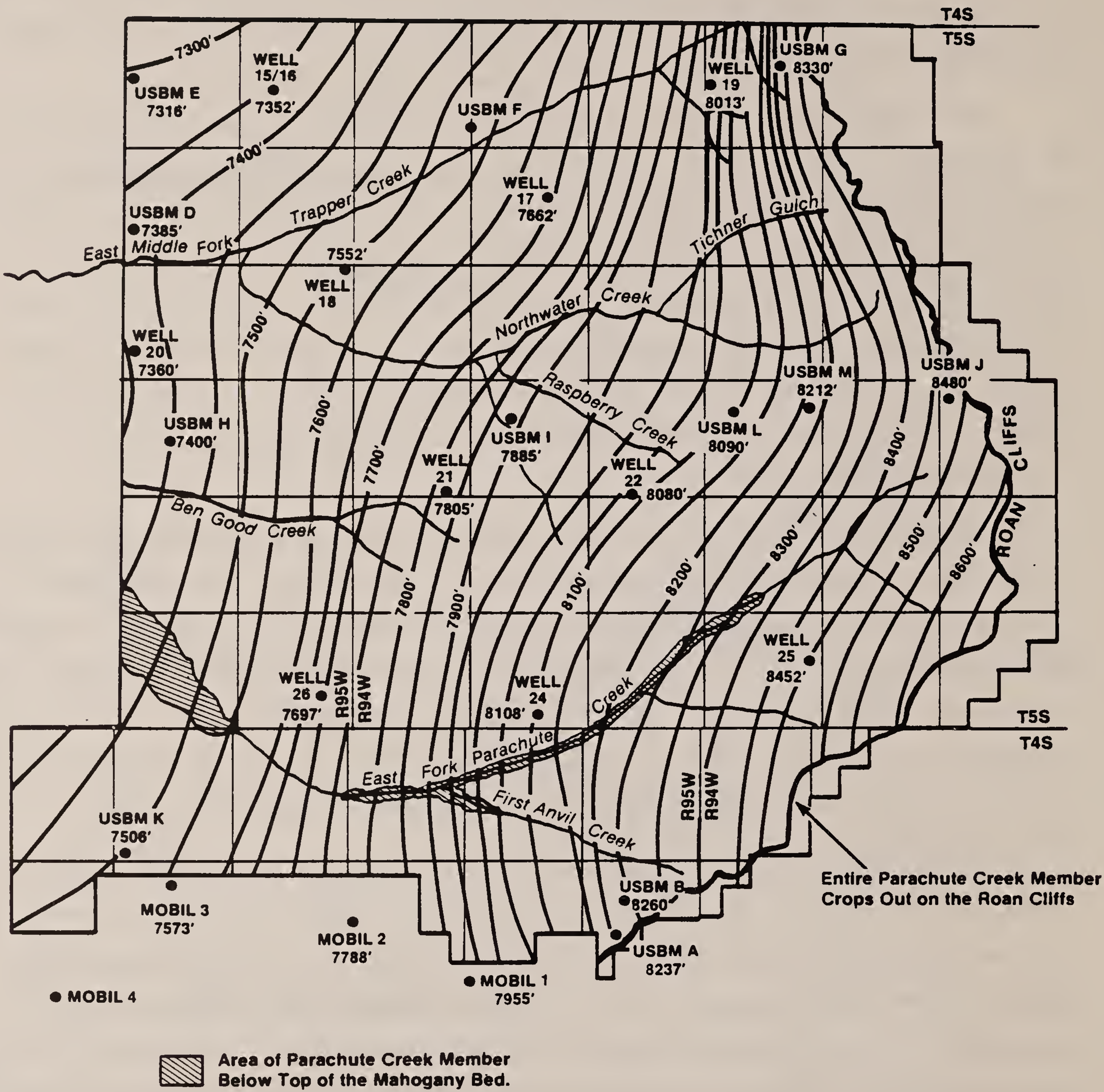


Figure 3-7. NOSR 1 Structure Contour - Top of the Mahogany Bed

3.5.1.3 Uinta Formation

The Uinta Formation is composed primarily of clastic near-shore lacustrine and alluvial sediments (Juhan, 1965). Brown, weathering, very fine to medium grained sandstone, and yellow to gray siltstones are the dominant lithologies, with minor amounts of mudstone, shale, and gray marlstone found near the formation base. The Uinta Formation marks the final regressive stage of Lake Uinta, when a predominently fluvial environment replaced the lacustrine environment.

On NOSR 1, the Uinta Formation forms the upland area and the brown rounded ridge tops. It ranges in thickness from 0 to more than 700 feet (Well 15/16). Original formation thickness is not known because the upper surface of this unit is an erosion surface. At its maximum, in the vicinity of the basin depositional axis, the Uinta Formation reaches 1,250 feet in thickness.

3.5.1.4 Quaternary Alluvium

Above the falls on East Fork Parachute Creek, the Quaternary alluvium on NOSR 1 ranges in size from sand to cobbles and is generally thin. Limited and localized auger boreholes show a range in the alluvial thickness from less than 5 feet to more than 20 feet (TRW, September 1980). Field observations, however, indicate that on average the thickness is closer to the minimum, and that the streams often flow directly on bed rock. Therefore, on NOSR 1, storage of water in the alluvium is not significant.

3.5.2 Geologic Structure

Figures 3-6 and 3-7, structural contour maps on the top of the Big Three and the top of the Mahogany bed respectively, show the structural form on NOSR 1. These horizons were chosen to help define outcrop stratigraphy of the upper Parachute Creek Member on NOSR 1, and are sufficiently separated to show that the structure in the Parachute Creek Member on NOSR 1 does not vary appreciably with increasing depth. The major structural feature is the change in strike of bedding from southward in the northeast part of NOSR 1, to westward in the southwest part. This general synclinal picture is modified by a low relief anticlinal nose which plunges northwesterly across the center of NOSR 1. The dip of the bedding is generally from 1° to 3° to the west, increasing to about 5° near the basin margin in the northeast corner of the Reserve (TRW, 1979).

No large faults have been identified on NOSR 1. However, a photogeologic evaluation of potential geologic hazards to development, identified one possible fault. This potential fault, located in the northeast quarter of Section 14, T. 5 S., R. 95 W., extends for approximately 1,500 feet and trends N 65° W. The expression of this possible fault is a slight offset on an aerial photo of a marlstone tongue in the Uinta Formation (TRW, 1980).

In addition to identifying a possible fault, the photogeologic evaluation mentioned above mapped numerous joints on NOSR 1. Sixty-three percent of the more than 200 joints observed have strikes between N 70° W and S 80° W. The major joint trend on the aerial photos is S 80° W to E-W. In the field, the major joint trend is approximately N 80° W, except along the northern edge of NOSR 1 where a trend of N 50°-60° W becomes pronounced. The major joints are generally vertical while some minor joints show dips of 50° to 60°. Joint spacing varies from less than 1 foot to more than 10 feet. Based on experience elsewhere in the Piceance Creek basin, it is probable that most joints do not cross major bedding planes (Tosco, written communication). To a large extent, groundwater flow on NOSR 1 will be heavily influenced by the regional jointing. Therefore, based on the trend of the jointing and the general dip on NOSR 1, groundwater will tend to flow generally westward.

4. CHARACTERISTICS OF THE HYDROLOGIC SYSTEM ON NOSR 1

4.1 INTRODUCTION

This section integrates the various hydrologic data gathered on NOSR 1 to establish the baseline characteristics of the hydrologic system. The system is composed of four major elements. These include precipitation (inflow), surface water (outflow and storage), groundwater (outflow and storage), and evapotranspiration (outflow). These four elements taken together establish the water balance for the hydrologic system on NOSR 1. This water balance is summarized in the following equation:

$$P = R + D + E_t - \Delta S$$

where,
- P = Precipitation
- R = Surface Water Runoff
- D = Deep Percolation or Groundwater Recharge
- E_t = Evapotranspiration
- ΔS = Changes in Soil Moisture

Precipitation (P) on NOSR 1 is a combination of rain and snowfall, and has been monitored since Water Year 1977. However, because of problems with the precipitation gages and the shorter period of snow measurements, reliable estimates of precipitation are only available since Water Year 1979.

Surface water runoff records are available since Water Year 1977. The surface water runoff (R) is primarily a combination of snowmelt runoff and baseflow supplied by groundwater discharge from springs.

Deep percolation (D) or recharge to the groundwater system can not be measured directly. However, since the groundwater system on NOSR 1 has not been significantly stressed by well discharge, it is assumed to be in a state of hydrologic equilibrium. This state implies that the rate of discharge equals the rate of recharge, and that no change in storage takes place. Therefore, surface water baseflow, which is groundwater discharge, should approximate deep percolation or recharge.

Evapotranspiration (E_t) is a combination of evaporation from water surfaces and moist soil, and transpiration from growing plants. For this study, evapotranspiration on NOSR 1 will be estimated using E_t values calculated by I.F. Wymore in 1974 for the different elevation zones and vegetation types in the upper Piceance Creek watershed, and then adjusting these values for the elevation and vegetation distributions on NOSR 1.

Changes in soil water (ΔS) on an annual basis are very small (Wymore, 1974). Therefore, for this study ΔS is assumed to be zero.

4.2 INFLOW INTO THE NOSR 1 HYDROLOGIC SYSTEM

4.2.1 Precipitation

NOSR 1 includes the headwater areas of all watersheds that contribute to the surface water discharge from the Reserve. Therefore, the only inflow into the NOSR 1 hydrologic system is contributed by precipitation.

4.2.1.1 Precipitation Gage Network Data

In September of 1976, the U.S. Geological Survey (USGS) agreed to assist the U.S. Navy in an inventory of the water resources and hydrologic system on NOSR 1, as part of a five year pre-development plan. As part of this assistance, the USGS agreed to install, operate, and maintain three precipitation gages on NOSR 1.

The USGS office responsible for these gages is:

U.S. Geological Survey
Water Resources Division
P.O. Box 2027
Grand Junction, Colorado 81502

The locations of the precipitation gages are shown in Figure 4-1. Table 4-1 lists various gage characteristics.

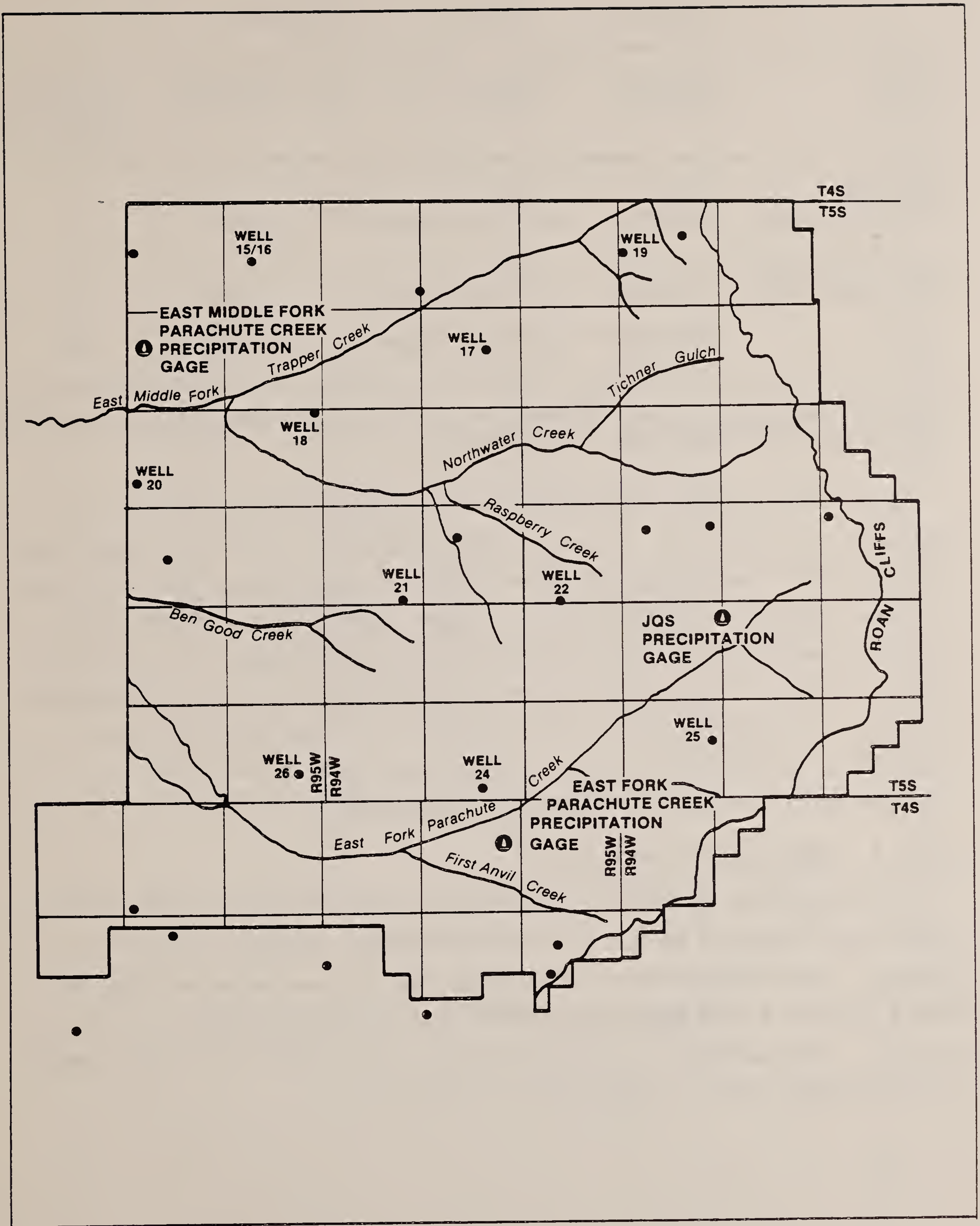


Figure 4-1. Index Map, NOSR 1 Precipitation Gages

Table 4-1. NOSR 1 Precipitation Gages

GAGE	USGS NO.	PERIOD OF RECORD	ELEVATION (Feet, msl)	THIESSEN WEIGHTING FACTOR (%)*
East Fork Parachute Creek	09092960	11/23/76-Present	8560	33
East Middle Fork Parachute Creek	09092830	11/23/76-Present	8300	35
JQS	09092950	12/20/76-Present	8840	32

*Thiessen Weighting Factor - Percent of total NOSR 1 watershed area for which gage records are considered representative.

Precipitation gage records for the three stations are compared in Figures 4-2 through 4-5. As can be seen, significant breaks in record have occurred since installation of these gages. In most cases, these data gaps were due to equipment malfunction. In other cases, severe winter weather prevented servicing the gages on schedule. However, using the comparative plots in Figures 4-2 through 4-5, it is possible to arrive at a reasonable estimate of spring/summer/fall precipitation by averaging daily values measured at the functioning gage or gages, and using these values to estimate precipitation at the non-functioning gage.

4.2.1.2 Snow Course Network Data

In addition to the three precipitation gages, the USGS established a single snow course on NOSR 1 to measure snow-pack thickness and water-content. This snow course is adjacent to the JQS precipitation gage and should provide a good check for recorded precipitation values at that station. Snow-pack data has been obtained at this snow course from January 1979 to present, and is summarized in Table 4-2.

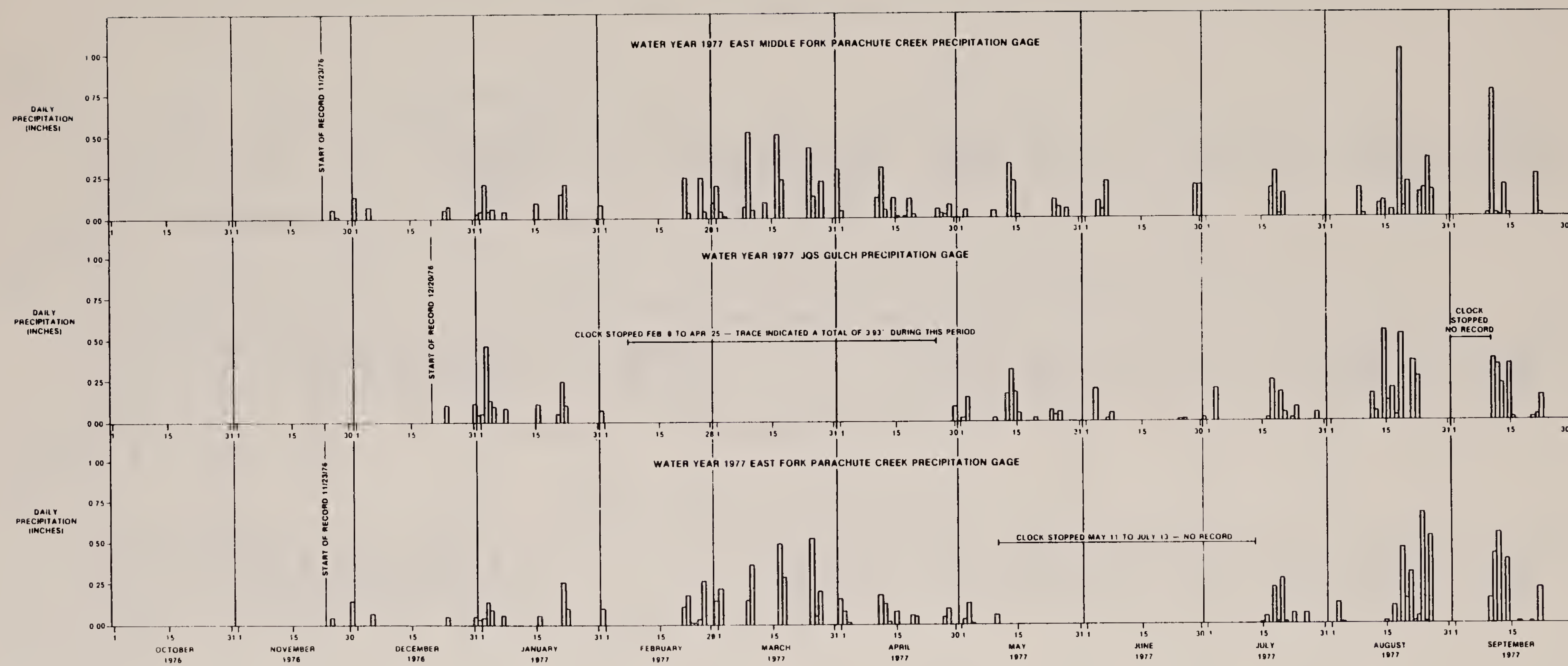


Figure 4-2. Comparative Plot of Daily Precipitation Records at the NOSR 1 Precipitation Gages at East Middle Fork Parachute Creek, East Fork Parachute Creek, and JQS Gulch, Water Year 1977

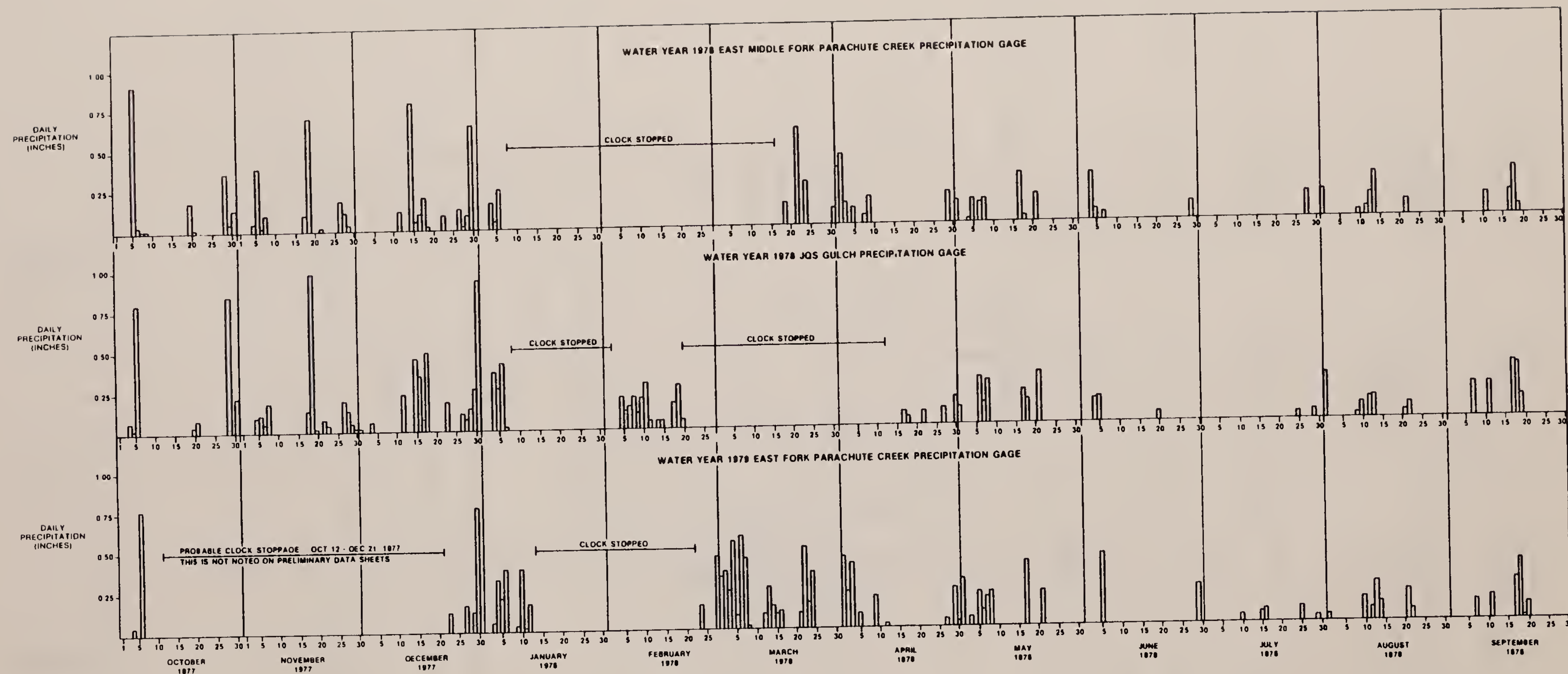


Figure 4-3. Comparative Plot of Daily Precipitation Records at the NOSR 1 Precipitation Gages at East Middle Fork Parachute Creek, East Fork Parachute Creek, and JQS Gulch, Water Year 1978

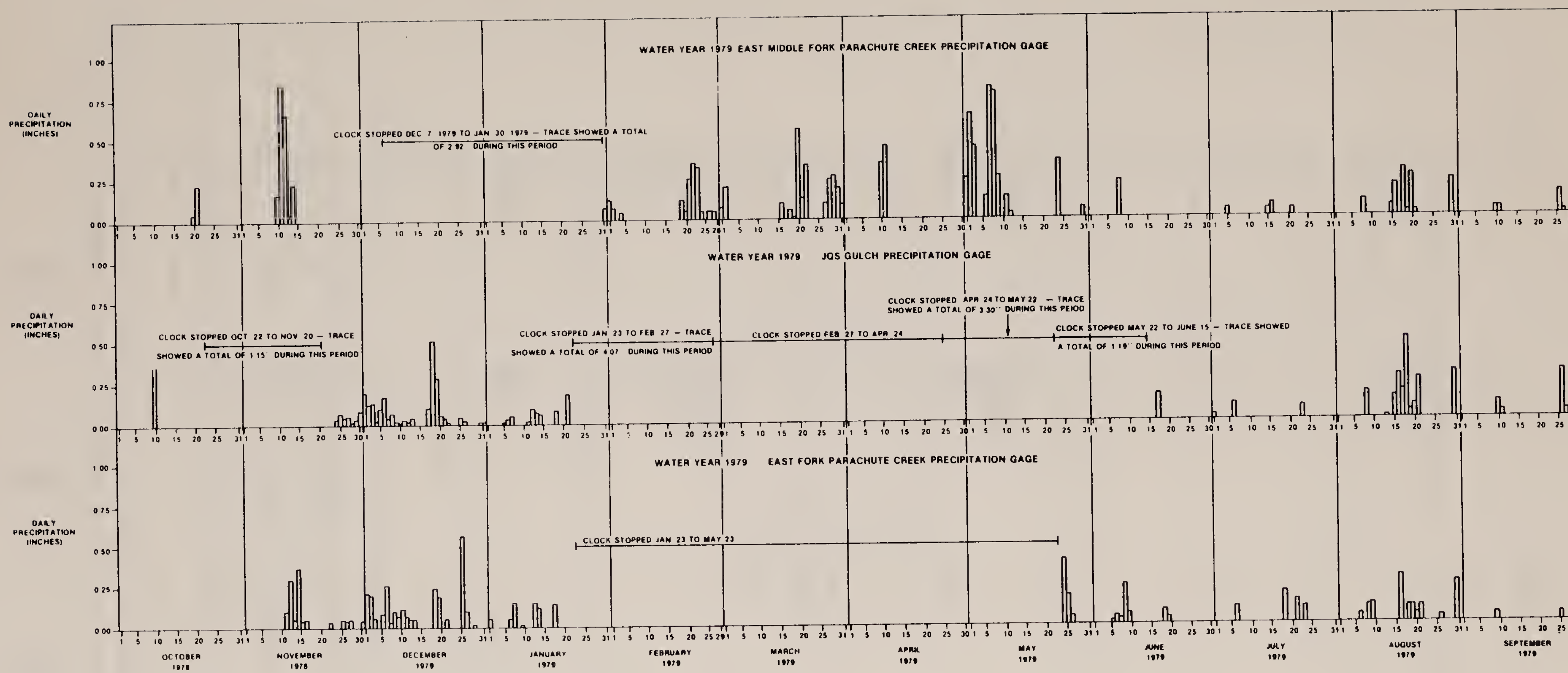


Figure 4-4. Comparative Plot of Daily Precipitation Records at the NOSR 1 Precipitation Gages at East Middle Fork Parachute Creek, East Fork Parachute Creek, and JQS Gulch, Water Year 1979

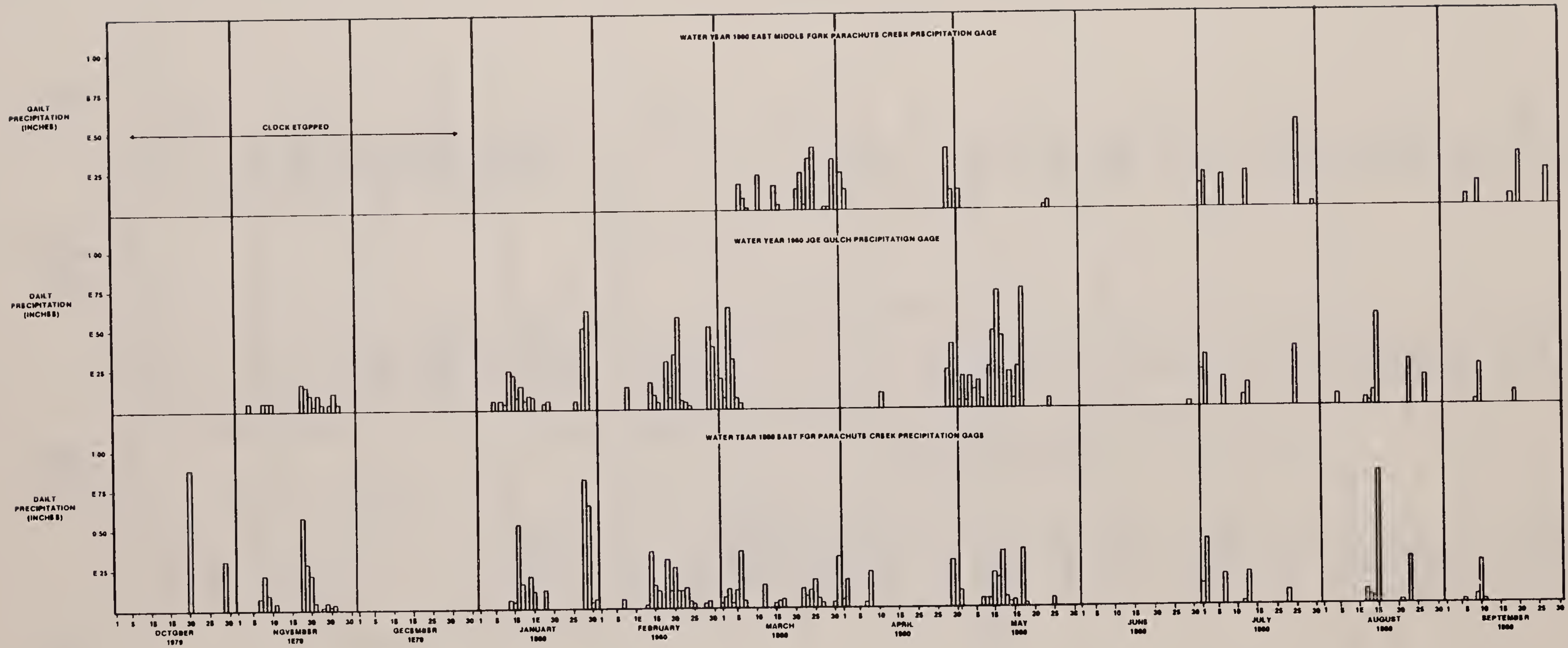


Figure 4-5. Comparative Plot of Daily Precipitation Records at the NOSR 1 Precipitation Gages at East Middle Fork Parachute Creek, East Fork Parachute Creek, and JQS Gulch, Water Year 1980

Table 4-2. Summary of USGS JQS Snow Course Data

Winter	Maximum Average Measured Snow Depth (Inches)	Maximum Average Measured Water Content (Inches)
1978 - 1979	58.4	20.7
1979 - 1980	59.4	22.1
1980 - 1981	27.5	6.4

Table 4-3 compares the snow-pack water-content measured by the USGS at the JQS snow course, with the precipitation recorded at the JQS precipitation gage for the same time period.

Table 4-3. Comparison of JQS Snow-Course Water-Content Data to JQS Precipitation Gage Records

Time Period	Snow Course Maximum Measured Water Content (Inches)	JQS Precipitation Gage Records (Inches)
Nov. 1978 - Apr. 15, 1979	20.7	2.87
Nov. 1979 - Apr. 15, 1980	22.1	7.80
Nov. 1980 - Apr. 15, 1981	6.4	Records not yet Available

As can be seen, there is a significant difference in the precipitation gage records and the snow course measurements. Reasons for this include:

- Snow bridging over the precipitation gage intake area
- Precipitation gage equipment malfunction due to temperature extremes
- Inability to service precipitation gage on regular schedule because of access problems

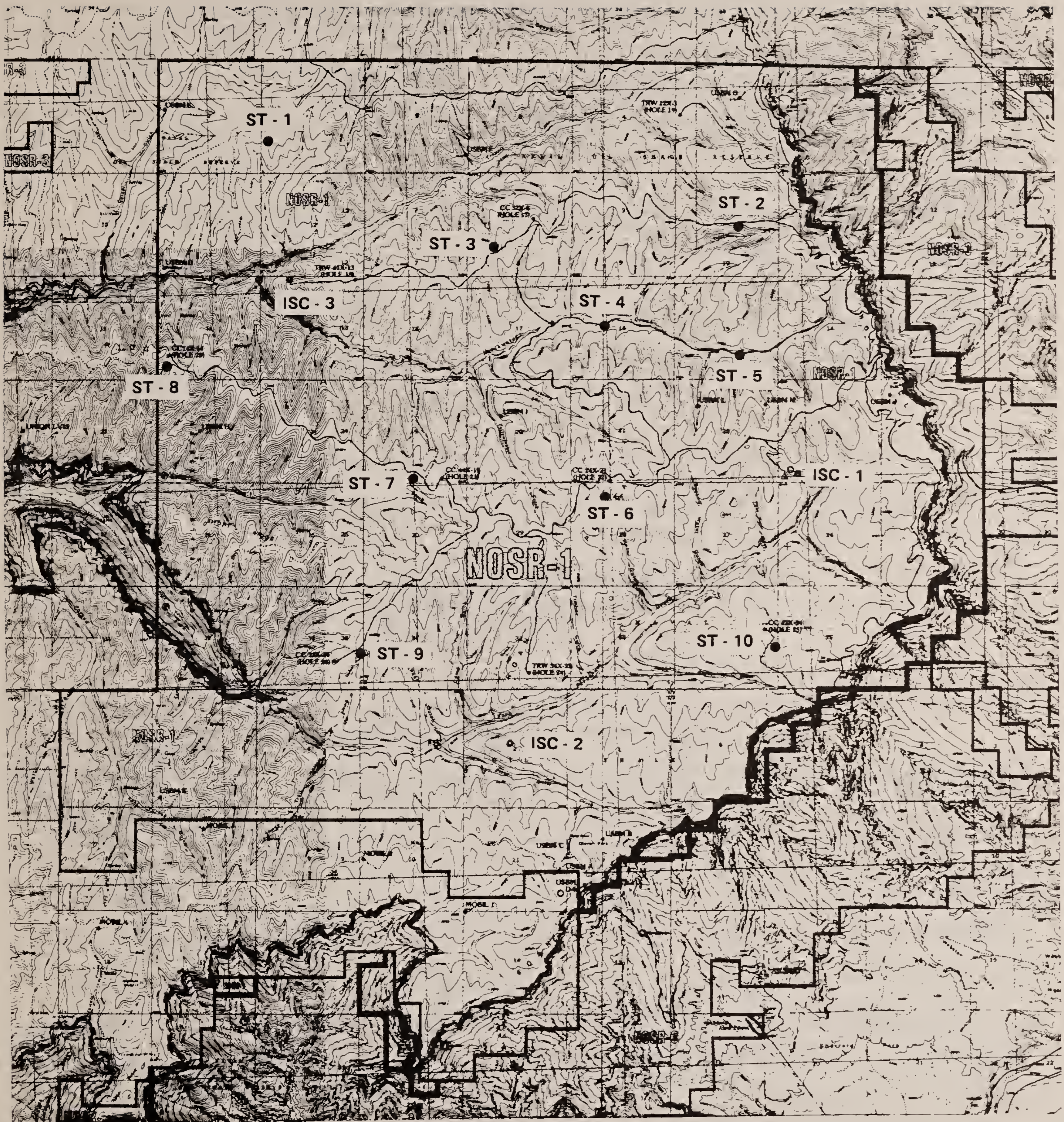
All of these problems are associated with the precipitation gage. Therefore during the winter snow accumulation period, snow course measurements should be considered the primary source of precipitation data.

Since snow course measurements were proven to be the most reliable source of winter precipitation data and because in excess of 60 percent of total annual precipitation comes during the winter, an expanded snow course network was installed by DOE/TRW in November 1980. This expanded network included twelve additional snow courses.

Two of these snow courses were established in the vicinity of precipitation gages and, together with the USGS snow course, make up the Index Snow Courses. The measurements from these index snow courses provide checks on the data recorded at the precipitation gages. The other ten snow courses established by DOE/TRW were set up to ensure that snow accumulation data was obtained from representative elevation zones for various aspects and cover conditions, and are identified as Snow Transects.

Figure 4-6 is a general index map of the present NOSR 1 snow reconnaissance network. Table 4-4 summarizes the 1980-1981 snow reconnaissance network data by elevation zone. Table 4-5 provides an estimated total snow pack water-content for the winter of 1980-1981.

The weighted average total 1980-1981 snow-pack water-content is approximately 4.6 inches. This is approximately 75% of the snow-pack water-content measured at Index Snow Course No. 1 (USGS JQS snow course) which was established in 1978 and has the longest period of record.



ST — Snow Transect
ISC — Index Snow Course

Figure 4-6. Index Map, NOSR 1 Snow Reconnaissance Network

Table 4-4. Summary of NOSR 1 Snow Reconnaissance Network Maximum Values, Winter 1980 - 1981

Elevation Zone (Feet)	Number of Samples	Maximum Snow Measurements								
		Snow Depth (Inches)			Water Content (Inches)			Density (%)		
		Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
9200-8800	49	19.0	6.0	19.8	7.0	3.0	5.2	50	16	28
8800-8400	62	35.5	4.0	17.3	8.5	2.0	4.7	50	20	28
8400-8000	25	29.5	4.0	17.0	7.0	2.0	4.3	50	19	28

Table 4-5. Estimated Total NOSR 1 Snow-Pack Water-Content, Winter 1980 - 1981

Elevation Zone, Feet	Approximate Percent of Total Area of NOSR 1	Average Water Content of Snow-Pack (Inches)	Weighted Average of Snow-Pack Water-Content (Inches)
9200-8800	26	5.2	1.35
8800-8400	41	4.7	1.93
8400-8000	30	4.3	1.29
Total	97	--	4.57

4.2.1.3 Estimated Total Annual Precipitation on NOSR 1

To estimate total annual precipitation on NOSR 1 for the periods of record, a combination of gage data and snow-pack water-content data is used. Table 4-6 summarizes the estimated total April through November precipitation gage data for Water Years 1977 through 1980.

USGS JQS snow course water-content data for Water Years 1979 and 1980 was previously summarized in Table 4-3. However, based on analysis of the 1980-1981 snow-pack data collected on the expanded snow reconnaissance network and on-going measurements for the Winter of 1981-1982, the water content values obtained at the USGS JQS snow course are considered high by approximately 25%. Table 4-7 summarizes the adjusted snow-pack water-content for the Winters of 1978-1979 and 1979-1980.

Table 4-8 combines the adjusted snow-pack water-content from Table 4-7, with the estimated spring/summer/fall precipitation from Table 4-6, to arrive at an estimated total annual precipitation on NOSR 1 of 24.4 and 25.2 inches for Water Years 1979 and 1980, respectively.

4.3 OUTFLOW FROM THE HYDROLOGIC SYSTEM

4.3.1 Surface Water

4.3.1.1 Drainage Description and Gage Network

Naval Oil Shale Reserve No. 1, with an area of approximately 50 square miles, is within the Parachute Creek drainage basin and includes the headwater area of the major tributaries of East Fork and East Middle Fork Parachute Creek. In late 1976, at the request of the Department of Energy, the USGS established five surface water gages on NOSR 1 to monitor both total surface water runoff and surface water quality. Two gages are located on the East Fork Parachute Creek drainage. The upstream gage is sited just downstream of the confluence with First Anvil Creek. The downstream gage is located downstream of East Fork Falls in East Fork Canyon at the western boundary of NOSR 1. Two gages are located on the East Middle Fork Parachute Creek drainage. The East Middle Fork drainage includes the upstream major tributaries of Northwater Creek and Trapper Creek.

Table 4-6. Estimated Total Spring/Summer/Fall Precipitation on NOSR 1 for Water Years 1977 through 1980

Water Year	Precipi- tation Gage	Total Estimated Spring/Summer/Fall (Apr to Nov Incl.) Precipitation (Inches)	Thiessen Weighting Factor* (%)	Weighted Precipitation (Inches)
1977	East Middle Fork	7.6	35	2.7
	East Fork	7.8	33	2.6
	JQS	7.0	32	2.2
TOTAL				7.5
1978	East Middle Fork	8.1	35	2.8
	East Fork	10.3	33	3.4
	JQS	10.0	32	3.2
TOTAL				9.4
1979	East Middle Fork	8.9	35	3.1
	East Fork	8.2	33	2.7
	JQS	9.7	32	3.1
TOTAL				8.9
1980	East Middle Fork	7.0	35	2.5
	East Fork	8.1	33	2.7
	JQS	10.5	32	3.4
TOTAL				8.6

*Thiessen Weighting Factor-Percent of total NOSR 1 area for which gage records are considered representative.

Table 4-7. Adjusted Snow-Pack Water-Content Data for the USGS JQS Snow Course for the Winters of 1978-1979 and 1979-1980

Winter	Measured Snow-Pack Water-Content (Inches)	Adjusted Snow-Pack Water-Content (Inches)
1978-1979	20.7	15.5
1979-1980	22.1	16.6

Table 4-8. Estimated Total Annual Precipitation on NOSR 1 for Water Years 1979 and 1980

Water Year	Estimated Spring/Summer/Fall Precipitation (Inches)	Estimated Winter Snow Pack Water Content (Inches)	Estimated Total Annual Precipitation (Inches)
1979	8.9	15.5	24.4
1980	8.6	16.6	25.2

The upstream gage on this drainage is sited on Northwater Creek, just upstream of its confluence with Trapper Creek. The downstream gage is approximately one mile west of the Northwater - Trapper confluence on the western boundary of NOSR 1. The fifth surface water gage monitors flow on the Ben Good Creek, a small tributary to East Fork. This gage is sited below the falls on Ben Good in East Fork Parachute Creek Canyon, approximately 0.2 mile upstream of its confluence with East Fork Parachute Creek. Figure 4-7 shows the geographic location of the five gages. Table 4-9 summarizes the location and types of data collected at each of the gages.

4.3.1.1.1 East Fork Parachute Creek

East Fork Parachute Creek drains the southern half of NOSR-1. It has its headwaters in JQS and Golden Castle Gulches, and flows westward.

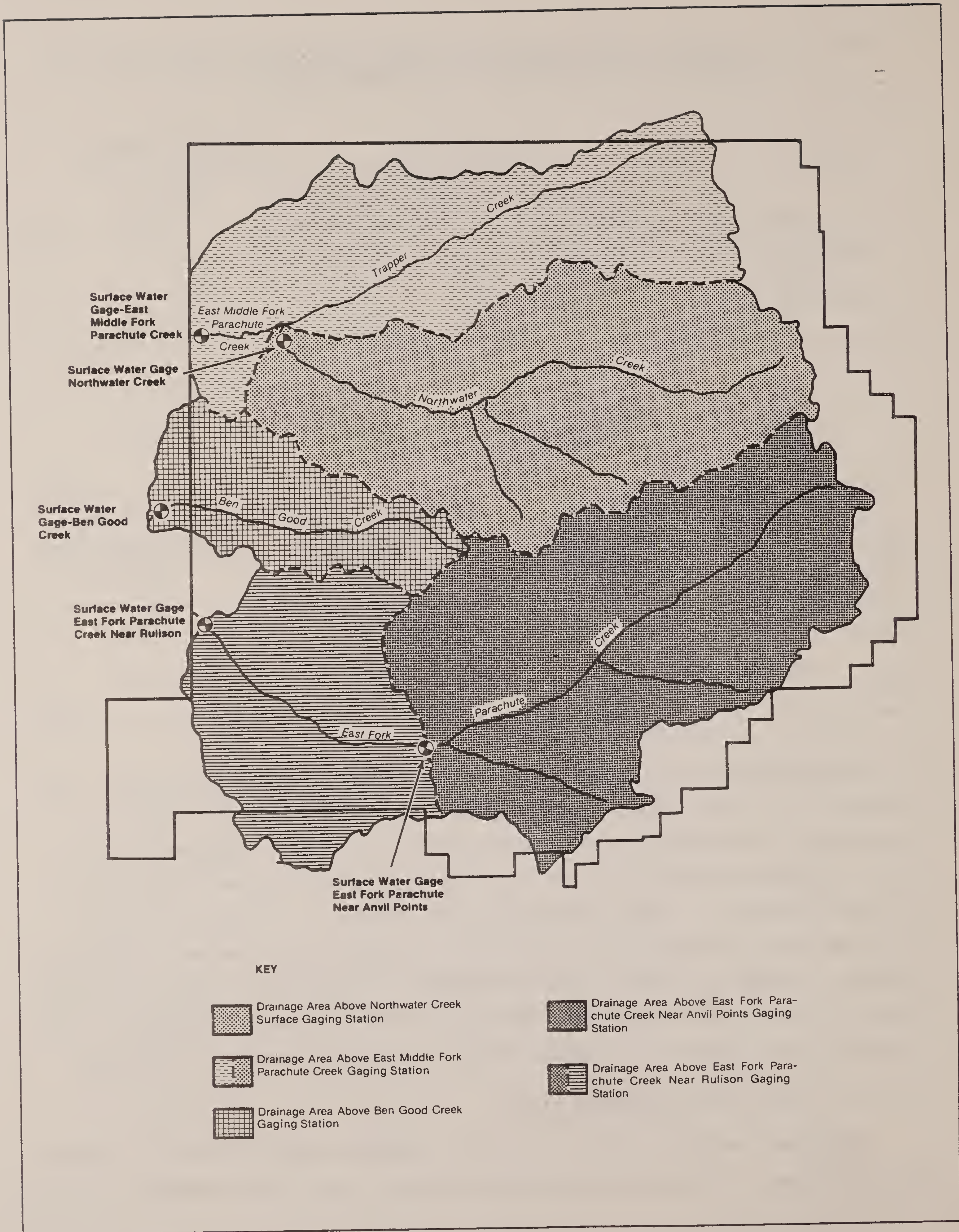


Figure 4-7. Index Map, NOSR 1, Surface Water Gages

Table 4-9. NOSR 1 Surface Water Gages

Gage Name	USGS Station No.	Location	Altitude of Gage (ft,msl)	Drainage Area (mi^2)	Data Collected
East Middle Fork Parachute Creek	09092850	At NOSR 1 Western Boundary	7,400	22.1	Discharge-Continuous record; daily values reported. Water Quality-Monthly sampling and analyses. Specific Conductivity-Hourly; mean daily values reported. Stream Temperature-Hourly; maximum and minimum daily values reported. Suspended Sediment-Daily or more often; daily sediment discharge (tons/day) reported.
Northwater Creek near Anvil Points, Colo.	09092830	At Confluence with East Middle Fork Parachute Creek (upstream of East Middle Fork Gage)	7,420	12.6	Discharge-Continuous record; daily values reported. Water Quality-Monthly sampling and analyses.
Ben Good Creek near Rulison, Colo.	09092980	Approximately 0.2 mile upstream of the confluence with East Fork Parachute Creek	6,880	4.04	Discharge-Continuous record; daily values reported. Water Quality-Monthly sampling and analyses.
East Fork Parachute Creek near Rulison, Colo.	09092970	At NOSR 1 Western Boundary	6,880	20.4	Discharge-Continuous record; daily values reported. Water Quality-Monthly sampling and analyses. Specific Conductivity-Hourly; mean daily values reported. Stream Temperature-Hourly; maximum and minimum daily values reported. Suspended Sediment-Daily or more often; daily sediment discharge (tons/day) reported.
East Fork Parachute Creek near Anvil Points, Colo.	09092960	At Confluence with First Anvil Creek upstream of East Fork nr. Rulison gage)	7,860	14.5	Discharge-Continuous record; daily values reported. Water Quality-Monthly sampling and analyses.

Tributaries on the north side of the drainage are 1 to 1 1/2 miles in length and generally flow due south. Major tributaries on the north side include Third Water Gulch, Camp Gulch, and Bull Gulch. Tributaries on the south side are 1 1/2 to 2 miles in length, and generally flow west-northwest. Major tributaries on the south side include First and Second Anvil Creeks, and Sheep Trail Hollow.

East Fork Parachute Creek flows across the lower Uinta Formation and the Parachute Creek Member of the Green River Formation above the B-groove. The Uinta Formation is confined to the ridge crests while the Parachute Creek Member outcrops in the lower reaches of the tributaries and along the entire length of East Fork. The thickest exposure of this unit is found in an isolated reach in East Fork Valley from just upstream of the confluence, with Second Water Gulch downstream to approximately 1 mile below the confluence with First Anvil Creek. In this reach, the Mahogany bed is exposed at or just above the stream bed.

4.3.1.1.2 East Middle Fork Parachute Creek

East Middle Fork Parachute Creek drains the northern half of NOSR 1 and consists of the tributary streams, and Trapper and Northwater Creeks. The northern tributary, Trapper Creek, drains an area of approximately 10 square miles. Tributaries to Trapper Creek range in length from less than 0.5 miles to approximately 2 miles. Northwater Creek, the southern tributary, drains an area of about 12 square miles. The major tributaries to Northwater Creek include Tichner Draw, and Yellow Jacket and Raspberry Creeks.

East Middle Fork Parachute Creek tributaries flow across the lower Uinta Formation and the Parachute Creek Member of the Green River Formation above the Wavey bed. The Parachute Creek Member outcrops in the headwater area of Trapper Creek. This unit then dips beneath the surface along the middle reach of Trapper for approximately 2 miles before cropping out again about 1 mile upstream from the confluence of Northwater and Trapper Creeks. The Parachute Creek Member crops out along the entire length of Northwater Creek. Outcrops in this watershed include all marker beds above the Wavey bed.

4.3.1.1.3 Ben Good Creek

Ben Good Creek drains a small area in the west-central part of NOSR 1 and is tributary to East Fork Parachute Creek. The surface water gage is located below the falls in East Fork Canyon. Ben Good Creek flows across the lower Uinta Formation and the Parachute Creek Member of Green River Formation above the Big Three marker. In September 1980, field reconnaissance of the Ben Good drainage area above the falls revealed no flow over the falls. A reconnaissance below the falls on the following day showed significant flow past the gage. Since there are no other significant surface water discharges above this gage and very little area to contribute localized sub-flow, it is probable that the bulk of the observed flow is contributed by direct groundwater discharge from bedrock. Stratigraphically the groundwater discharge probably issues from the water-bearing zone below the R-6 zone.

4.3.1.2 Annual Surface Water Runoff Characteristics

4.3.1.2.1 East Fork Parachute Creek

East Fork Parachute Creek provides approximately 50 percent of the total annual runoff from NOSR 1. Figure 4-8 (shown on page 4-23) illustrates the annual hydrographs for both gages on this stream. Baseflow is approximately 1.0 ft^3/sec, with the annual peak flow occurring in April-June in response to snow melt. Approximately 50 percent of the total annual discharge occurs during this period of peak flow. Baseflow is provided by numerous springs in the lower part of the Uinta Formation and Parachute Creek Member of the Green River Formation. Tables 4-10 and 4-11 summarize the discharge data gathered at both gages on East Fork for Water Years 1977 through 1980.

Table 4-10. Summary of Discharge Data - East Fork Parachute Creek near Anvil Points Surface Water Gage

Water Year	Mean Daily Discharge (ft^3/sec)	Maximum Daily Discharge (ft^3/sec)	Minimum Daily Discharge (ft^3/sec)	Total Annual Discharge (acre-ft)
1977	0.67	1.9	0.07	485
1978	6.85	119.0	0.17	4960
1979	13.7	180.0	0.39	9900
1980	11.6	136	0.82	8450

Table 4-11. Summary of Discharge Data - East Fork Parachute Creek near Rulison Surface Water Gage

Water Year	Mean Daily Discharge (ft^3/sec)	Maximum Daily Discharge (ft^3/sec)	Minimum Daily Discharge (ft^3/sec)	Total Annual Discharge (acre-ft)
1977	0.06	1.9	0.0*	40
1978	7.3	107	0.0*	5270
1979	12.5	220	0.26	9090
1980	12.6	161	0.00*	8790

* Probable ice condition at gage.

Flow past the upstream gage in some instances is higher than flow past the downstream gage, opposite of what one would expect. The following are three reasons for this, all of which probably contribute.

- Loss to groundwater system
- Significant evaporation of water going over the falls
- Underflow in the thick alluvium of East Fork Canyon

Accurate gaging of the relative importance of each of these factors would require a gage immediately above the falls.

4.3.1.2.2 East Middle Fork Parachute Creek

East Middle Fork Parachute Creek accounts for approximately 45 percent of the total annual runoff from NOSR 1. Figure 4-9 (shown on page 4-23) illustrates the annual hydrographs for both gages on this drainage. Baseflow is less than 1.0 ft^3/sec with the annual peaks occurring from April to June in response to snow melt. Approximately 50 percent of the total annual discharge occurs during this period of peak flow. In addition, from 60 to 75 percent of the total annual runoff from this watershed is contributed by the Northwater Creek tributary. Tables 4-12 and 4-13 summarize the discharge data gathered at the gages on this drainage for Water Years 1977 through 1980.

Table 4-12. Summary of Discharge Data - Northwater Creek near Anvil Points Surface Water Gage

Water Year	Mean Daily Discharge (ft^3/sec)	Maximum Daily Discharge (ft^3/sec)	Minimum Daily Discharge (ft^3/sec)	Total Annual Discharge (acre-ft)
1977	0.57	3.1	0.01	414
1978	4.15	84	0.20	3000
1979	7.45	130	0.20	5390
1980	7.46	81	0.50	5420

Table 4-13. Summary of Discharge Data - East Middle Fork Parachute Creek near Rio Blanco Surface Water Gage

Water Year	Mean Daily Discharge (ft^3/sec)	Maximum Daily Discharge (ft^3/sec)	Minimum Daily Discharge (ft^3/sec)	Total Annual Discharge (acre-ft)
1977	0.68	10	0.20	489
1978	7.19	95	0.18	5200
1979	11.6	150	0.26	8410
1980	10.6	118	0.57	7690

4.3.1.2.3 Ben Good Creek

Ben Good Creek, with its drainage area of 4.04 square miles, accounts for approximately 10 percent of the total NOSR 1 watershed area and contributes less than 5 percent of the total annual runoff. Figure 4-10 shows the annual hydrographs for this gage. Those periods of no flow recorded during the winters may be indicative of ice conditions at the gage rather than no flow. As mentioned previously, Ben Good Creek valley above the falls contributed no flow past the end of June in 1980. In June 1981, a spring reconnaissance was done in the Ben Good Creek valley above the falls. During this reconnaissance, there was no flow over the falls. This suggests that, except for the snow-melt runoff from the beginning of April to the beginning June, all flow on Ben Good Creek is supplied by direct groundwater discharge from below the falls. Table 4-14 summarizes the discharge data gathered at this gage for Water Years 1977 through 1980.

Table 4-14. Summary of Discharge Data - Ben Good Creek near Rulison Surface Water Gage

Water Year	Mean Daily Discharge (ft^3/sec)	Maximum Daily Discharge (ft^3/sec)	Minimum Daily Discharge (ft^3/sec)	Total Annual Discharge (acre-ft)
1977	0.0	1.40	0.0	0.9
1978	0.37	7.0	0.0	269
1979	1.10	11.0	0.0	796
1980	1.09	11.0	0.0	789

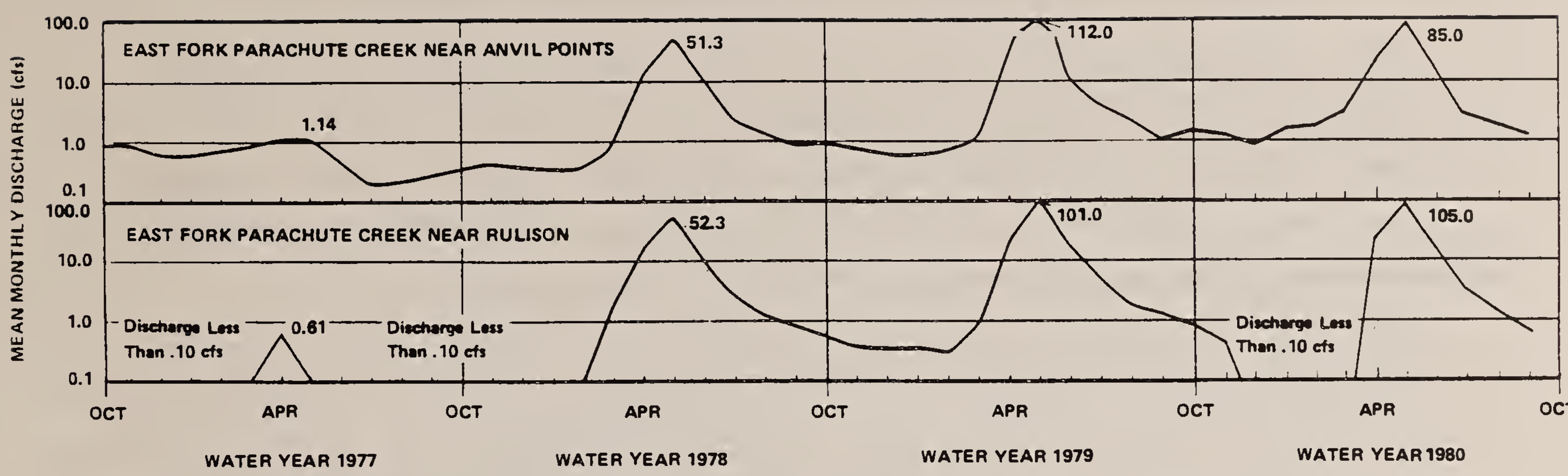


Figure 4-8. Annual Hydrographs for the East Fork Parachute Creek near Anvil Points and East Fork Parachute Creek near Rulison Surface Water Gages

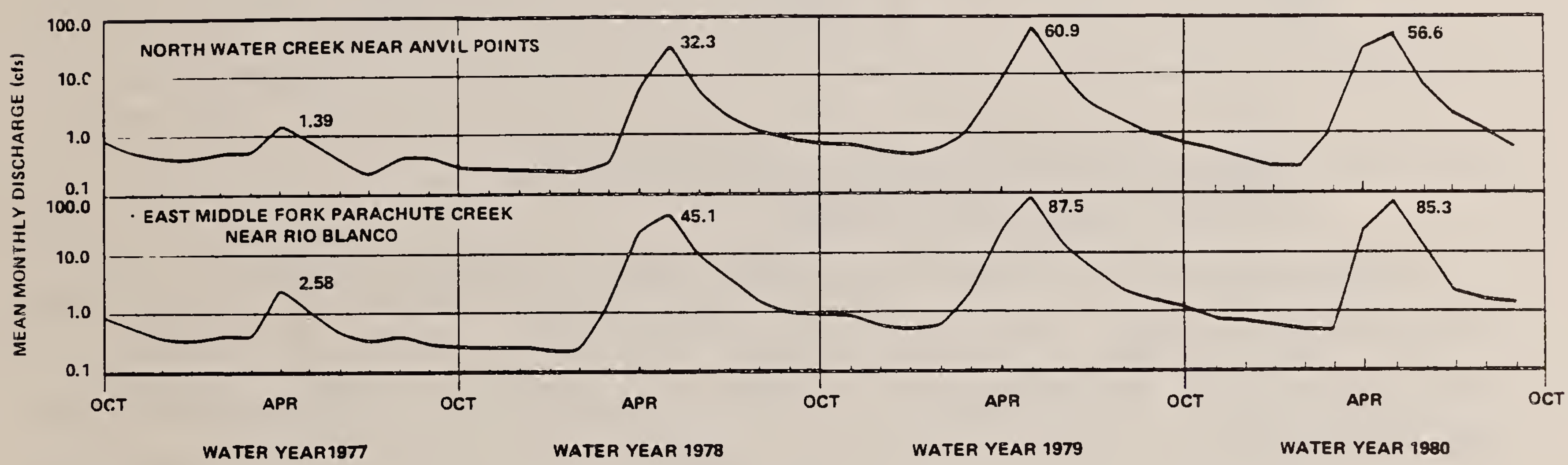


Figure 4-9. Annual Hydrographs for the Northwater Creek near Anvil Points and the East Middle Fork Parachute Creek near Rio Blanco Surface Water Gages

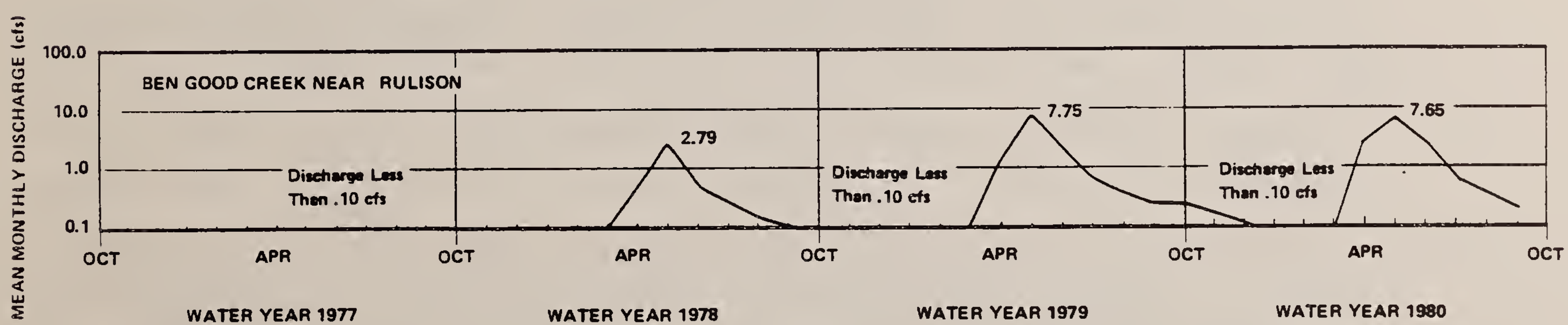


Figure 4-10. Annual Hydrographs for the Ben Good Creek near Rulison Surface Water Gages

4.3.1.2.4 Estimated Total Annual NOSR 1 Surface Water Runoff

Total estimated annual runoff from NOSR 1 was determined by summing the flow past the East Middle Fork Parachute Creek, Ben Good Creek, and East Fork Parachute Creek near Rulison surface water gages. Total drainage area above these gages is 46.54 mi^2 (29,786 acres). Table 4-15 summarizes the estimated total annual surface water runoff from NOSR 1.

Table 4-15. Estimated Total Annual Surface Water Runoff from NOSR 1

Water Year	Total Annual Discharge (Acre-Ft)	Total Annual Discharge (Area-Inches)
1977	529.9	0.21
1978	10,739.0	4.32
1979	18,296.0	7.37
1980	17,269.0	6.96

4.3.1.2.5 Comparison of Precipitation and Discharge for Water Years 1979 and 1980

In Section 4.2.1.3, Table 4-8 presents the estimated total annual precipitation on NOSR 1 for Water Years 1979 and 1980. Table 4-16 compares that data with the estimated total surface water runoff from NOSR 1 for the same water years.

Table 4-16. Comparison of NOSR 1 Estimated Total Annual Precipitation to Estimated Total Annual Discharge

Water Year	Estimated Total Annual Precipitation (Inches)	Estimated Total Annual Discharge (Area-Inches)
1979	24.4	7.37
1980	25.2	6.96

This table indicates that between 25 and 30 percent of precipitation, the single source of inflow into the NOSR 1 hydrologic system, leaves the system as surface water runoff. The remaining 70 to 75 percent is lost primarily through evapotranspiration. An estimate of NOSR 1 evapotranspiration will be addressed in Section 4.3.3 of this report.

4.3.1.3 Rainfall - Runoff Relationships

Figures 4-11 and 4-12 show typical storm hydrographs recorded at the gages on East Fork and East Middle Fork Parachute Creek on July 2-3, 1980. Preceeding precipitation records show a storm event on July 1, 1980 which contributed an average of 0.21 inch of rainfall over the NOSR 1 area. There is no perceptable increase in discharge past the gage in response to this event, indicating that all precipitation for the July 1 rainfall was lost to runoff through some combination of infiltration, ground saturation and soil storage, and evapotranspiration. The specific storm event which caused an increase in discharge past the surface water gage occurred between 1800 and 2000 hours on July 2, 1980. This storm event contributed an average rainfall of 0.33 inches over NOSR 1.

Discharge past the upper gage on East Fork Parachute Creek increased from a baseflow of approximately 6.0 ft^3/sec to a peak of 9.1 ft^3/sec. Lag time, or the time from the middle of the storm event to the center of the runoff peak, was approximately 9 hours. Direct runoff volumes less baseflow past the gage for this storm event was equal to approximately 0.003 area-inches. Discharge past the downstream gage increased from a baseflow of approximately 4.9 ft^3/sec to a peak of 9.2 ft^3/sec. Lag time was about 10 hours. Direct runoff volume, less baseflow past this gage for this storm event, was also equal to about 0.003 area-inches. Therefore, on the East Fork Parachute Creek drainage, total direct runoff from this one storm event equaled approximately 1.0 percent of the total area precipitation.

On the East Middle Fork Parachute Creek drainage, discharge past the Northwater Creek gage increased from a base flow of approximately 3.2 ft^3/sec to a peak flow of 4.7 ft^3/sec. Lag time was approximately 8 hours. Direct runoff volume, less baseflow past the gage, was equal to approximately 0.001 area-inches. Discharge past the East Middle Fork Parachute Creek near Rio Blanco gage increased from a base flow of 4.7 ft^3/sec to a peak flow of 6.3 ft^3/sec. Lag time was approximately 11 hours. Direct runoff of volume less baseflow past the gage was equal to approximately 0.001 area inches. At both gages on this watershed, total direct runoff from this one storm event represents less than 1.0 percent of the total area precipitation.

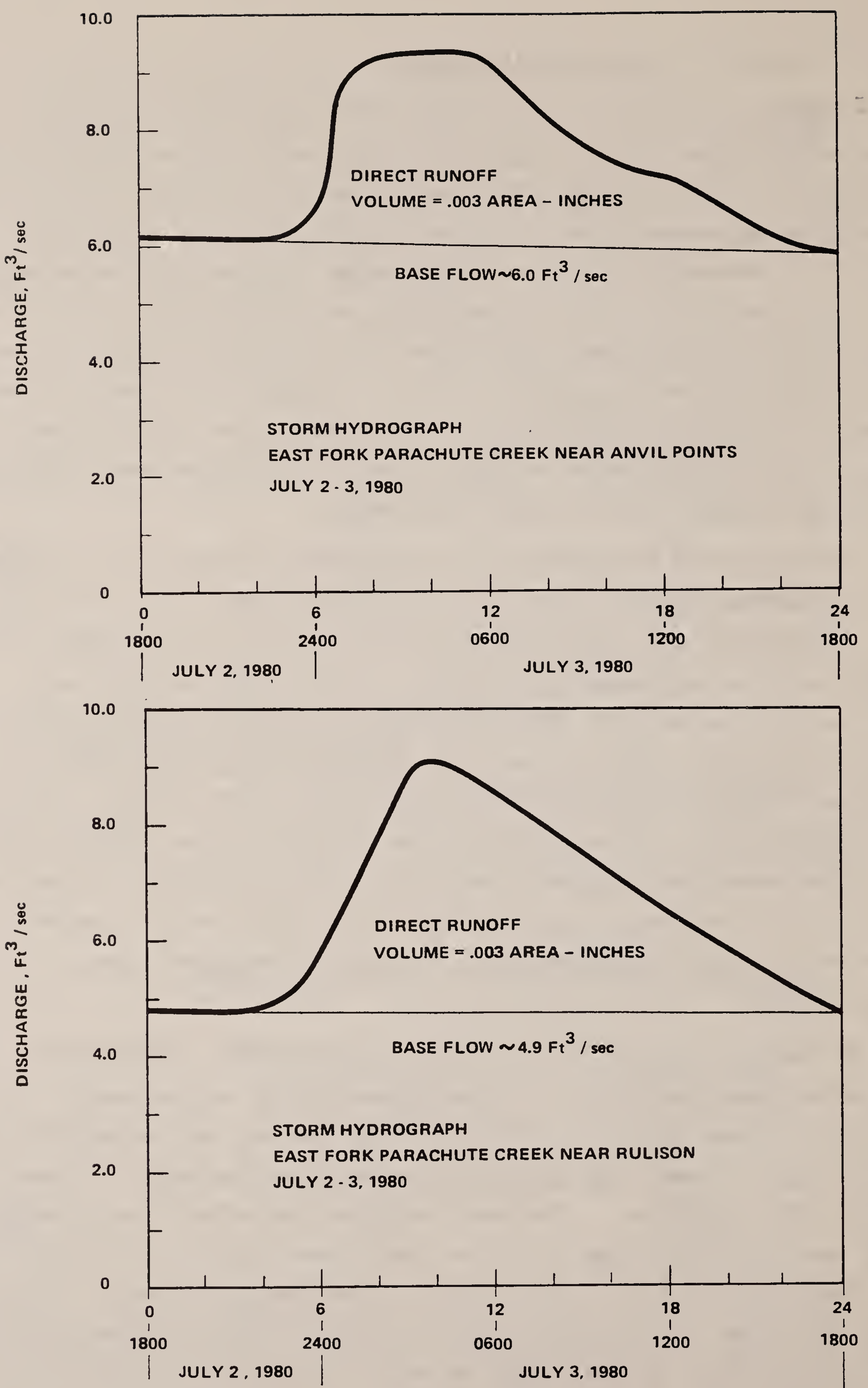


Figure 4-11. Storm Hydrographs, July 2-3, 1980. NOSR 1 Surface Water Gages, East Fork Parachute Creek near Anvil Points and near Rulison

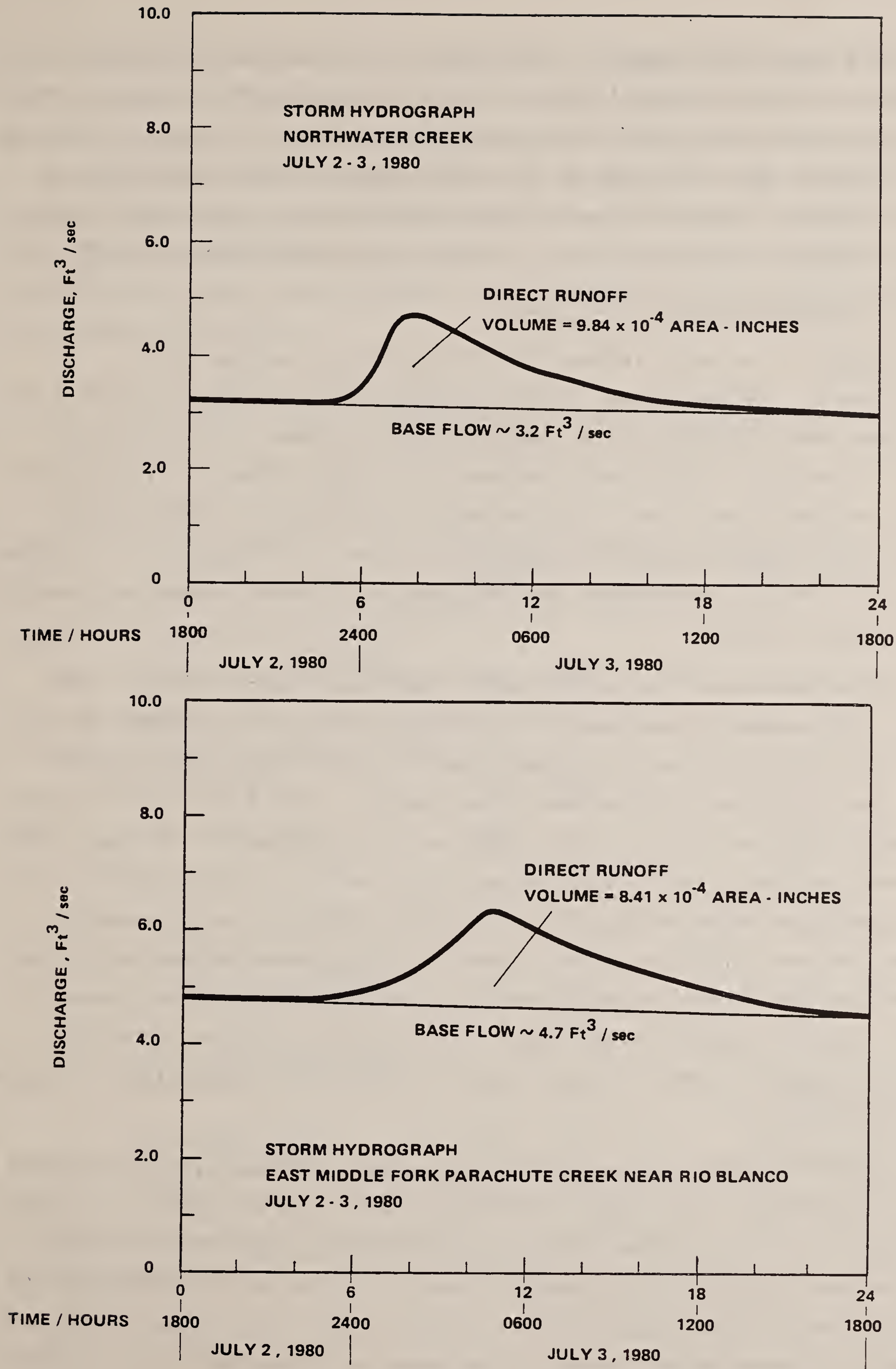


Figure 4-12. Storm Hydrographs, July 2-3, 1980. NOSR 1 Surface Water Gages, Northwater Creek and East Middle Fork Parachute Creek near Rio Blanco.

These storm hydrographs indicate that a typical general rainfall event on NOSR 1 contributes very little to surface water runoff. Localized thunderstorms undoubtably would produce much larger runoff. However, existing data indicates that this type of localized, high intensity rainstorm is rare on NOSR 1. Therefore, on an annual basis, normal non-winter precipitation probably contributes about 1.0 percent to total annual runoff.

4.3.1.4 Estimated Baseflow on NOSR 1

On NOSR 1, the only inflow into the hydrologic system is precipitation. As was shown in the previous section, very little of the non-winter precipitation leaves the hydrologic system as surface water runoff. Therefore, the primary components of total annual surface water runoff include direct runoff from snowmelt and baseflow. Given these general characteristics of the hydrologic system on NOSR 1, it is felt that analysis of annual hydrographs for the gages will yield a good estimate of total annual baseflow.

To estimate baseflow leaving NOSR 1 for Water Years 1979 and 1980, annual hydrographs of mean monthly discharge values were plotted for the East Fork Parachute Creek near Anvil Points, East Middle Fork Parachute Creek near Rio Blanco and Ben Good Creek gages. Data from the East Fork Parachute Creek near Anvil Points gage were used instead of the data from the "near Rulison" gage because these records were of better quality. It was assumed that mean monthly discharge values for the months August through February directly reflect baseflow. For March through July, the mean monthly discharge values represent a combination of direct snowmelt runoff, delayed release from storage, and baseflow. Estimates of the baseflow component were obtained using the hydrograph separation techniques described below.

For this report, two separation techniques were employed to estimate a range of baseflow at the gages. The separation technique used to estimate the upper limit of baseflow involves projecting the baseflow recession line, between August and September, backward in time on the hydrograph to a point one month after the peak flow. An arbitrary line is then drawn from February to connect with the end of the baseflow recession line. Identifying the lower limit of baseflow involves simply projecting a line from the February mean monthly discharge value to the August value. Mean monthly baseflow for March through July fall between these lines. Figure 4-13 is the annual hydrograph of mean monthly discharge values at East Fork Parachute Creek for Water Year 1979, showing the separation techniques used to estimate a range for baseflow. Table 4-17 summarizes the estimated range of total annual baseflow leaving NOSR 1 during Water Years 1979 and 1980. This table indicates that between 8 to 15 percent of the total surface water runoff leaving NOSR 1 during Water Years 1979 and 1980 was contributed by baseflow.

Table 4-17. Estimated NOSR 1 Annual Baseflow for Water Years 1979 and 1980

Water Year	Surface Water Gage	Estimated Range of Annual Base Flow	
		Acre-Feet	Area-Inches
1979	East Fork Parachute Creek near Anvil Pt.	772 - 1429	0.71-1.31
	East Middle Fork Parachute Creek near Rio Blanco	630 - 1050	0.53-0.89
	Ben Good Creek	80 - 173	0.37-0.80
	TOTAL	1482 - 2652	0.59-1.07*
1980	East Fork Parachute Creek near Anvil Pt.	919 - 1363	0.84-1.25
	East Middle Fork Parachute Creek near Rio Blanco	722 - 902	0.61-0.76
	Ben Good Creek	65 - 105	0.30-0.48
	TOTAL	1706 - 2370	0.69-0.95*

* Weighted Average

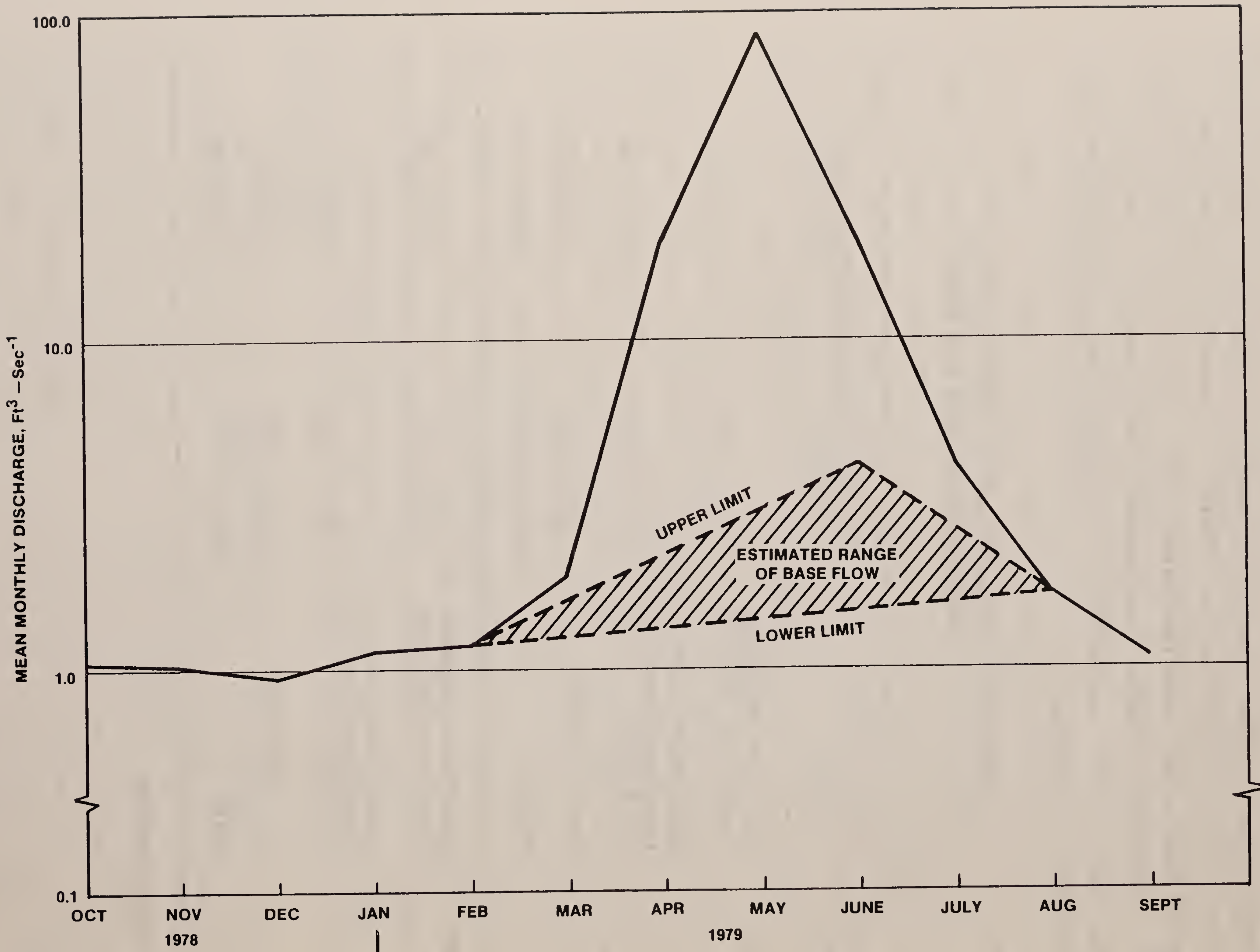


Figure 4-13. Annual Hydrograph Showing Estimated Range of Baseflow, Water Year 1979, East Fork Parachute Creek

Since very little groundwater development has taken place on NOSR 1, the groundwater system is essentially in a state of hydrologic equilibrium. This state of equilibrium implies that the rate of discharge from the system (surface water baseflow) is equal to the rate of recharge (deep percolation) with no change in storage. Therefore, the estimated range of baseflow for Water Years 1979 and 1980 approximates the groundwater recharge for these two years.

4.3.1.5 Surface Water Quality

Water quality samples are collected and analyzed for all five surface water gages on or adjacent to NOSR 1 by the U.S. Geological Survey. Samples are taken periodically throughout the year, and analytical results for all samples through 1981 have been obtained.

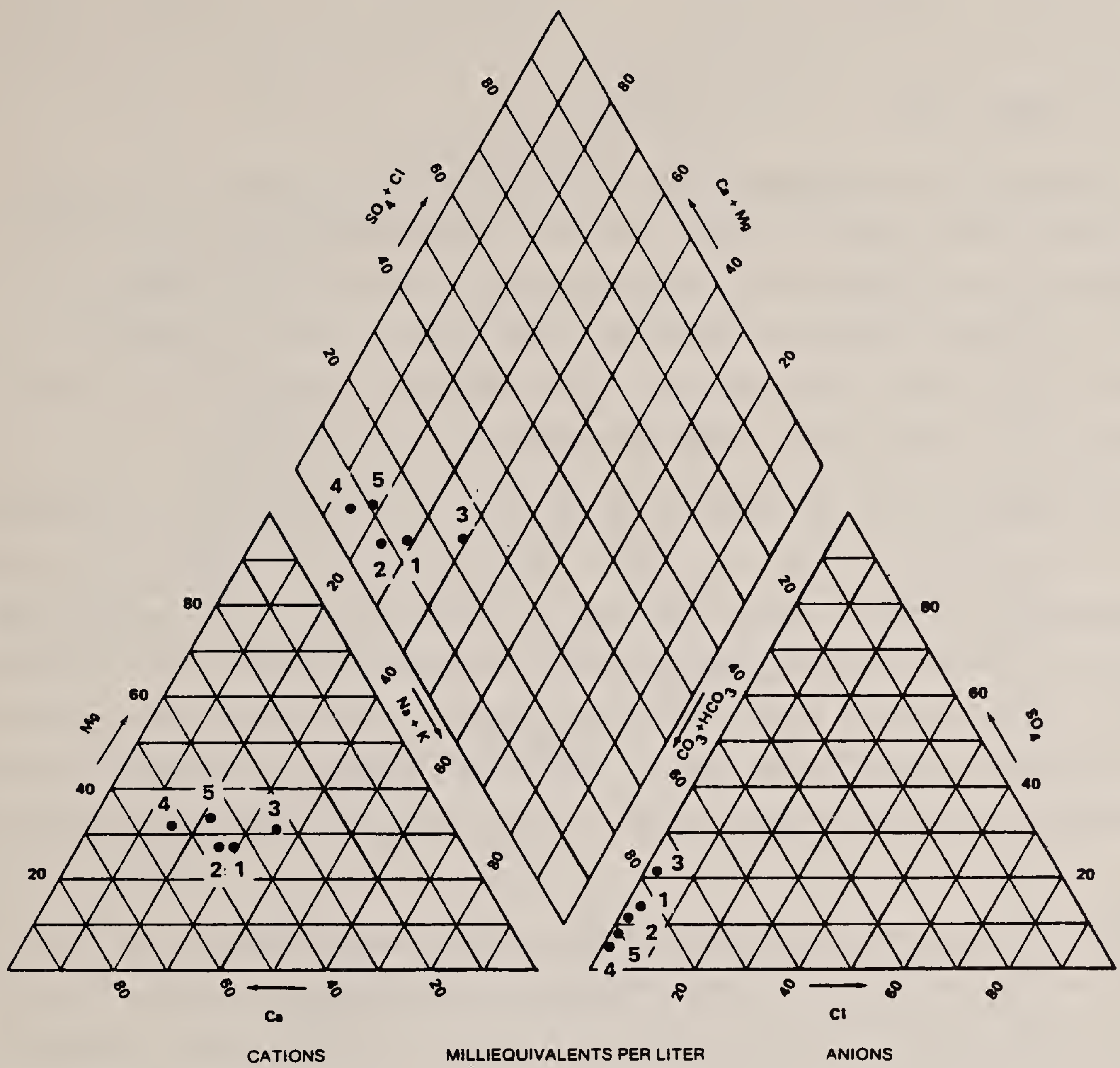
The quality of surface waters on NOSR 1 is good. Standards for drinking water or agricultural supplies are not exceeded anywhere on the Reserve. Sodium adsorption ratios are less than 2 and, according to U.S. Salinity Laboratory Standards (1954), only a low- to medium-salinity hazard exists. Therefore, surface water on NOSR 1 is well suited for irrigation. Total dissolved solids range from 225 mg/l to just under 400 mg/l, with annual station averages from 265 to 350 mg/l. The best quality water, based on dissolved solid concentrations, is found in the East Fork of Parachute Creek and the highest dissolved solids concentrations are recorded at the Ben Good gage. This suggest a slight north to northwestward increase in dissolved solids concentration across the Reserve.

A tabluation of yearly averages for major dissolved constituents for Water Year 1980 is given in Table 4-18. The table illustrates the ranges that led to the interpretations given above and was used to type the water quality on a Piper Diagram shown in Figure 4-14. All of the stations except East Fork Parachute Creek near Anvil Points are classed as mixed-cation-bicarbonate waters. At the East Fork near Anvil Points gage, the water can be classified as a calcium-bicarbonate water. As was noted in the Interim Hydrology Report for NOSR 1 (1980), the concentration of dissolved solids at the East Fork Parachute Creek near Rulison is less than that at the upstream gage. It should be noted that the downstream gage is located in an alluvial valley below East Fork falls and probably receives

Table 4-18. Yearly Average Values of Major Constituents from Chemical Analyses of Surface Water Samples from NOSR 1 During Water Year 1980

	East Middle Fork Parachute Creek near Rio Blanco, Colo.		Northwater Creek near Anvil Points, Colo.		Ben Good Creek near Rulison, Colo.		East Fork Parachute Creek Near Anvil Points, Colo.		East Fork Parachute Creek near Rulison, Colo.	
Constituent	mg/l	epm*	mg/l	epm*	mg/l	epm*	mg/l	epm*	mg/l	epm*
Ca	50.25	2.507	51.1	1.55	48.7	2.43	53.4	2.66	49.2	2.144
Mg	19.25	1.584	19.25	1.584	25	2.06	20.0	1.646	19.1	1.575
Na + K	34.45	1.475	32.75	1.411	44.72	1.93	20.48	0.87	22.61	0.973
Total Cations		5.581		5.545		6.416		5.819		4.692
SO_4	40	0.83	31.86	0.663	57.0	1.19	20.2	0.421	23	0.479
Cl	2.23	0.063	1.86	0.052	2.98	0.084	1.44	0.041	1.43	0.037
Carbonate	291.1	4.77	294.4	4.825	298.8	4.897	287.8	4.717	266.6	4.369
Total Anions		5.663		5.541		6.168		5.178		4.884
TDS	307		296		350		276.6		267	

*epm = equivalents per liter



SURFACE WATER GAGE NUMBER	TOTAL DISSOLVED SOLIDS mg/l
1	307
2	296
3	350
4	277
5	267

1. **East Middle Fork Parachute Creek, near Rio Blanco, Colorado.**
2. **Northwater Creek near Anvil Points, Colorado.**
3. **Ben Good Creek near Rulison, Colorado.**
4. **East Fork Parachute Creek near Anvil Points, Colorado.**
5. **East Fork Parachute Creek near Rulison, Colorado.**

Figure 4-14. Piper Diagram Showing Water Quality of Surface Water at Gages on NOSR 1.

contributions of more dilute water from the alluvium and from drainages to the south and southwest of NOSR 1. In addition, field evidence indicates evaporation loss of calcium carbonate occurs as the water in this creek goes over the falls.

Figure 4-15 is a comparative view of the water quality at 3 gages. The figure shows that all water from the reserve has essentially the same character. When compared to similar graphs presented by Coffin, et al., (1971) for other streams in Piceance Creek basin, the water quality at NOSR 1 shows that calcium, not sodium, is the dominant cation. Also, other streams in the basin have larger percentages of sulfate.

The water at the Ben Good Creek gage, also located below a waterfall and in an alluvial valley, has higher concentrations of magnesium, sulfate, strontium, and flouride than found at the other gages. This water type is more characteristic of the bedrock water quality as described in Section 4.3.2.5. The Ben Good Creek falls are usually dry except during snowmelt and rainstorms, and a large part of the flow probably originates as direct groundwater discharge through seeps in the slope wash and talus below the falls.

The slightly more calcium carbonate water at the upper East Fork gage is also reflected in the spring discharge points along reaches of this creek in the vicinity of First and Second Anvil Creeks. Here, calcium carbonate deposits are often found in the vicinity of springs, reflecting groundwater which is nearly saturated with respect to calcium carbonate. This is a common occurrance in northern Piceance Creek basin (Robson and Saulnier, 1981).

Trace element concentrations are generally low at all gages, with elevated values of strontium being the only exception. Strontium concentrations are generally between 0.5 and 1.0 mg/l, with values greater than 1.0 mg/l noted at Ben Good Creek. Elevated values of strontium are consistently found throughout Piceance Basin (Weeks, et al., 1974; Saulnier, 1978; Robson and Saulnier, 1981) and again reflect the influence of bedrock contact. Additionally, much of the baseflow for the creeks on NOSR 1 is maintained by springs, which also have high levels of strontium throughout the basin (Saulnier, written communication, 1981).

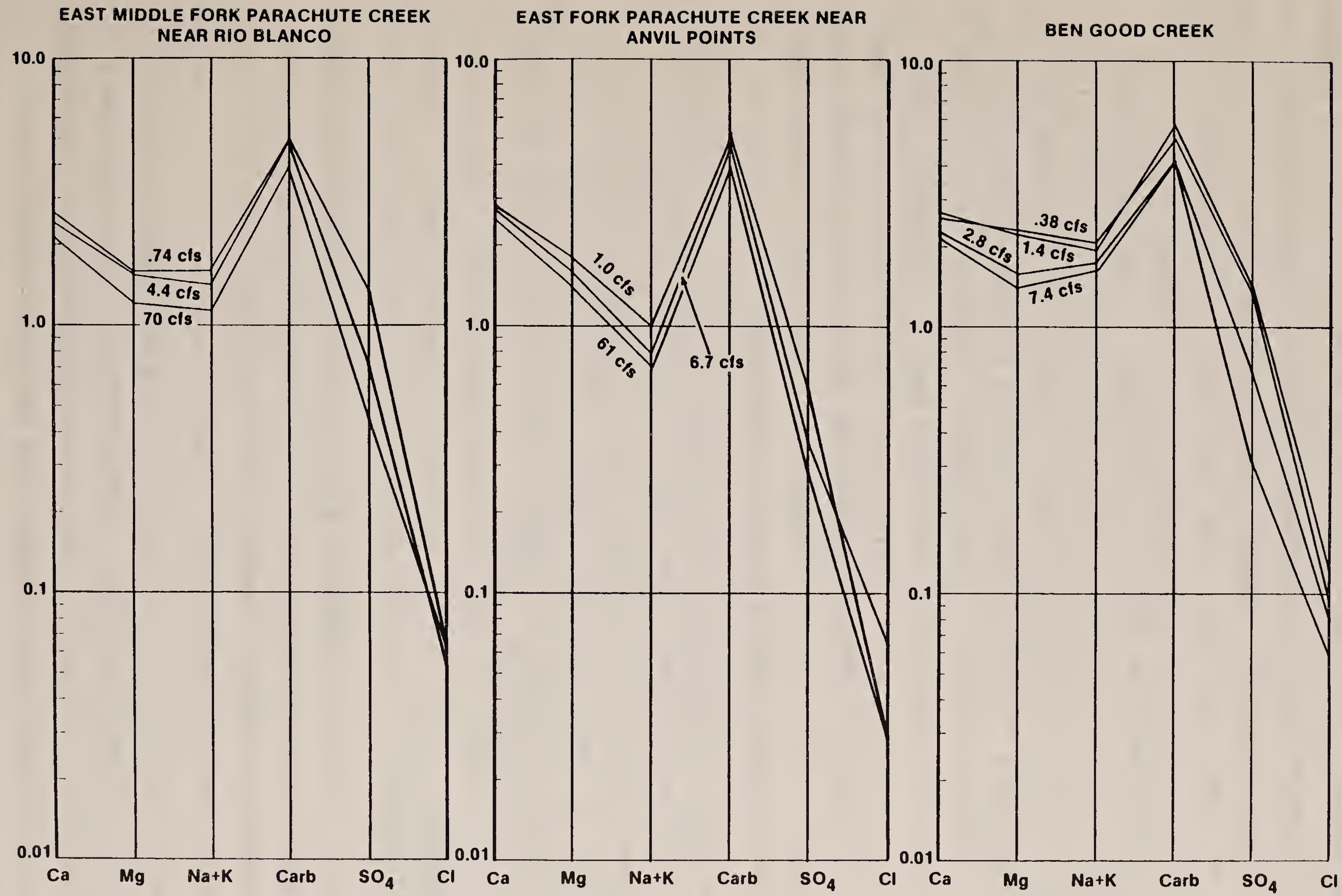


Figure 4-15. Graphs Showing the Chemical Character of Three Surface Water Gaging Stations on NOSR 1

The data presented in the section on surface water runoff indicates that discharge at the surface water gages is quite low except for peak flows during snowmelt. This fact is reflected in the water quality graphs in Figure 4-14 which show that increasing discharge reduces the concentrations of dissolved species. However, the decreases noted are only slight and not always consistent. The lack of wide variation and relatively high dissolved solids concentrations throughout the year suggests that the bedrock on NOSR 1 is well weathered and readily contributes dissolved material to surface water and water moving in the soil zone. The marlstones and calcium carbonate cements in the bedrock are primarily responsible for the dominantly calcium bicarbonate character of the water. Although snowmelt is the predominant source of surface water on NOSR 1 and snow in Piceance Creek basin has a specific conductance less than 20 micromhos/cm (Saulnier, written communication 1981), melting snow is usually acidic (pH 5 to 6) and probably has direct access to dust, loose soil, and weathered rock in order to raise dissolved solids concentrations to greater than 200 mg/l even at peak flow conditions.

Sediment data is available at the gage on East Middle Fork Parachute Creek (U.S. Geological Sruvey, Water Resources Data for Colorado, 1976-1980). Sediment discharge in tons/day ranges from near zero to approximately 200 tons per day during peak snowmelt, which occurs in April and May. The concentration drops off rapidly after snowmelt and is less than 2 tons/day from June though early April.

4.3.2 Groundwater

4.3.2.1 Background

Seven core holes were drilled on NOSR 1 in 1977 and three more were drilled in 1978. These core holes were drilled primarily to evaluate the oil shale resource on NOSR 1. However, these core holes have also been used to evaluate the existing groundwater system.

Limited aquifer testing, including jet tests and drawdown/recovery pump tests, was performed during the initial drilling. The testing and subsequent completion of several core holes as observation wells was done using a two-aquifer model which assumed that two water-bearing units existed in the Uinta and Green River Formations separated by the Mahogany zone acting as an aquitard or aquiclude. Data from the 1977 and 1978 testing programs are not included in this report. The 1977 data was previously reported by the U.S. Geological Survey to the Department of the Navy. The 1978 data was reported to the DOE in May 1979 in the Final Report of Hydrologic Testing Program on NOSR 1 for the Period 15 August 1978 to 28 October 1978.

Field operations were suspended in 1979-80 and during that hiatus a detailed review was done on all geologic and hydrologic data available. The results of this detailed review and re-evaluation of NOSR 1 data led to the identification of four water-bearing zones on the Reserve. These four water-bearing zones are graphically depicted in Plates 1 through 4. Plate 1 is a northwest-southeast cross section across NOSR 1. Plates 2, 3, and 4 are east-west cross sections.

As shown on the sections, the upper-most zone includes the Uinta Formation and the upper part of the Parachute Creek Member of the Green River Formation. This zone is generally unconfined and its confining base is somewhere in the 150 foot interval containing the Big Three, Stillwater, and 4-Senators rich zones of the Parachute Creek member. Zone 2 is located in the vicinity of the A-groove. This zone is generally confined to the lean zone between the Mahogany bed at its base and the richer beds above. Zone 3 is located in the vicinity of the B-groove. This zone is generally confined to the lean zone between the base of the Mahogany zone and the top of the R-6 zone. Zone 4 lies in the L-5 zone. The underlying confining layer includes the rich beds in the upper part of the R-5 rich zone, and the overlying confining layer is near the base of the R-6 rich zone.

4.3.2.2 Field Procedures and Analytical Methods

The groundwater data collection program began with a monitor-well network temporarily completed to collect data from above and below the Mahogany zone. The subsequent determination that there were four water-bearing zones meant that the existing wells had to be modified, and that additional data concerning potentiometric head, water quality, and aquifer characteristics were needed to verify this new concept. These goals were met by the following measures:

- Isolation of the water-bearing zones using packers, submersible pumps, and retrievable bridge plugs

- Pump testing of individual zones to collect data for calculating aquifer transmissivities and to collect samples for water quality analysis

- Permanent completion of each well to isolate the individual water-bearing zones for water level measurement as part of continued monitoring studies.

The water level drawdown/recovery data was obtained during pump testing using downhole transducers (Lynes Sentry MK-9E, 0-500 psi) which relayed the data to a surface recording unit (Lynes Digital Surface Recorder). Supplementing the transducers were electric water level indicators (Fisher M-Scopes) and downhole airlines. An M-Scope or airline, or in some cases a transducer, was used to monitor the water level above the uphole packer to assure effective zone isolation from overlying aquifers during Zones 2, 3, and 4 pump tests.

Despite the electronic problems, the transducer data was reasonable and valid interpretations were obtained. The testing periods were chosen on the basis of previous work and on preliminary pump start-up exercises designed to check pump operations and initial zone response.

At the end of each pump test, water samples were collected for laboratory analysis. Field measurements of pH, temperature, and specific conductance were performed during testing and when water samples were collected. The samples were field-preserved and sent immediately for laboratory analysis.

Head response data as measured by the transducers and M-scopes were analyzed by standard techniques. Because these were single well tests without observation wells, the analysis method for drawdown and recovery data was the Jacob modification of the Theis non-equilibrium well formula. The Jacob modification is used when "time" is very large or when the distance from the pumping well is small, as in the case of a single well. Under these conditions, the series solution to the non-equilibrium well formula becomes truncated, allowing semi-logarithmic paper to be used in the analysis. This analysis involves plotting drawdown versus the log of pumping time.

Values of transmissivity were then calculated for each straight line segment of the plots using the following simplified solution:

$$T = \frac{264\ Q}{\Delta S}$$

where, T = transmissibility in gal/day-ft.
Q = constant pumping rate in gal/min
ΔS = slope of the graph, or the difference in drawdown over one log cycle

The transmissivities calculated for each segment were consecutively numbered T_1 and T_2. The T_2 value is the one which most accurately reflects the true formation parameters because the segment of the graph from which T_2 is derived is further in time from the onset of pumping or recovery, and more closely reflects steady-state conditions. In cases where only one line was drawn, T with no subscript is used for transmissivity. In one test, Well 20, Zone 1, Test 2, a third break in slope and straight-line segment was noted and the third segment parameters used are subscripted with a 3. In this case, a highly fractured system is indicated with different values of transmissivities indicated as the cone of depression intercepts successive fractures or groups of fractures.

The analysis of aquifer tests by the Jacob's approximatation also involves observing the pattern of changes in slope of the straight-line segments of the semi-logarithmic time drawdown plots. A steepening of slope indicates a negative boundary condition, such as an impermeable barrier or the interception of fewer water-filled fractures by the cone of depression. When time drawdown plots become flatter, a positive boundary condition is indicated. A positive boundary condition represents recharge to the aquifer. On NOSR 1, positive boundaries probably reflect a change from a confined to an unconfined condition or the interception by the cone of depression of an increased number of fractures.

Recovery data was analyzed in a similar fashion by plotting residual drawdown (measured recovery) versus ratio of time since pumping started divided by time since pumping stopped. As with drawdown data, the semi-logarithmic plots (with time plotted on the log scale) can be analyzed using the equation shown above.

Time-ratio recovery plots can be used to estimate limitations of aquifers and the presence of recharge boundaries or variations in storage coefficients. Abscissa intercepts between 1 and 2 indicate variation in storage and abscissa intercepts greater than 3 indicate the possibility of a type of recharge effect (Johnson, 1972). When a residual-drawdown curve is displaced so that the ordinate intercept is less than 0, incomplete recovery, a characteristic of a limited aquifer, is indicated. Plots based on recovery may be more accurate because these data are less affected by in-hole conditions and mechanical perturbations of pump operation.

Some wells were tested by injecting known quantities of water into an isolated water-bearing zone and monitoring recovery of water level in response to that stress. These injection tests are considered analagous to pump (drawdown) tests, and the head build-up and recovery data were analyzed using the same methodology as that used for the pump test data. In the following sections, tables and figures summerize the transmissivities and hydraulic conductivities for each zone.

4.3.2.3 Aquifer Parameters

The following sections present a summary of the aquifer parameters calculated from pump and injection testing for Zones 1, 2, 3, and 4 carried out on NOSR 1 during the 1980 and 1981 field seasons. In general, the test results reveal responses typical of fractured media. Low transmissivities and hydraulic conductivities were measured in all zones, but no zone has a uniform response. All drawdown and recovery curves show breaks in slope which, in the majority of cases, indicate negative boundaries. Wells 18, 20, and 22 show positive boundary responses and are discussed in detail in the section below. Reliable storage coefficient values could not be estimated for the individual zones because observation wells were not present near the pumping/injection test holes.

The results of aquifer testing indicate that the rocks on NOSR 1 are not highly productive and have low values of transmissivity and hydraulic conductivity. Results of geophysical logging and examination of cores further indicate that the marlstones and siltstones of the Green River and Uinta Formations have low primary permeabilitiy, and that productive sections are restricted to thin fracture zones or individual fractures. Thus, a small percentage of a tested interval may contribute the majority of water to the pumping well. In addition, graphical analyses of the drawdown and recovery data show that the water-bearing zones behave as limited aquifers in most cases, and any sustained future pumping should be carried out at low discharge rates, preferably less than 15 and 25 gallons per minute. All water-bearing zones appear to be confined, except Zone 1 which appears to be semi-confined in the recharge areas.

4.3.2.3.1 Zone 1

Table 4-19 presents a summary of the aquifer parameter data obtained from pump tests on Zone 1. Representative aquifer parameter data is shown in Figure 4-16. Except for Well 22, all calculated transmissivities and hydraulic conductivities are extremely low. As can be seen from the "Remarks" column on Table 4-19, test analysis of recovery data indicated that water-bearing Zone 1 is a limited aquifer which can be pumped dry in a short period of time with a large pump. The drawdown curves are also characteristic of fractured reservoirs with negative boundaries encountered during pumping. This situation typically results from successive draining of water-bearing fractures during the widening of the cone of depression. Wells 22 and 24 have the largest transmissivities and hydraulic conductivity values. The analysis of the drawdown data indicates a positive boundary is present near these two wells. There are no large streams or bodies of water whose presence near these wells could result in this affect. The most likely explanation for the phenomenon is that Zone 1 in these areas is a semi-confined aquifer which was drawn down to unsaturated conditions during pumping. Such a situation would result in the positive boundary indications and larger transmissivities noted in the analysis.

4.3.2.3.2 Zone 2

Table 4-20 presents a summary of the aquifer parameter data obtained from pump and injection tests in Zone 2. Representative aquifer parameter data is shown on Figure 4-17. The calculated transmissivities and hydraulic conductivities are all low and non-uniformly distributed over the reserve. Wells 20, 22, and 26 displayed such rapid drawdown that the pump had to be shut down in less than 10 minutes, thus preventing collection of interpretable data.

Table 4-19. NOSR 1, SUMMARY OF AQUIFER TESTS FOR ZONE 1

WELL NO.	TEST NO.	TEST TYPE	INTERVAL TESTED (Feet Below Ground Surface)	TRANSMISSIVITY, T — DRAWDOWN (gpd/ft)	DRAWDOWN (ft^2/day)	RECOVERY (gpd/ft)	RECOVERY (ft^2/day)	RANGE OF HYDRAULIC CONDUCTIVITY, K (ft/day)	REMARKS
15/16	1	Pump	507*	T=33	T=4.4	T_1=21 T_2=9	T_1=2.8 T_2=1.2	.003-.009	Analysis indicates limited aquifer.
	2	Pump	507	T=22	T=2.9	T=13	T=1.7	.004-.006	
	3	Injection	507	T_1=50 T_2=22	T_1=6.7 T_2=2.9	T=18	T=2.4	.005-.015	
17	1	Pump	665*	T_1=306 T_2=156	T_1=40.9 T_2=20.8	T_1=235 T_2=73	T_1=31.4 T_2=9.8	.055-.231	Analysis indicates limited aquifer.
	2	Pump	665			T_1=185 T_2=68	T_1=24.7 T_2=9.1	.051-.139	
18	1	Pump	523*	T=37	T=4.9	T_1=100 T_2=14	T_1=13.4 T_2=1.9	.009-.063	Zone almost completely drawn down in 10 minutes.
19	1	Injection	256*	T=30	T=4.0	T=55	T=7.4	.031-.058	Analysis indicates limited aquifer.
	2	Injection	256	T=56	T=7.5	T=24	T=3.2	.025-.058	
20	1	Pump	597*	T=39	T=5.2	T=14	T=1.9	.008-.021	Analysis indicates limited aquifer.
21	1	Pump	551*	T_1=84 T_2=12	T_1=11.2 T_2=1.6	T_1=42 T_2=11	T_1=5.6 T_2=1.5	.008-.057	Analysis indicates limited aquifer.
	2	Pump	551	T=39	T=5.2	T=16	T=2.1	.011-.026	
22	1	Pump	517*	T_1=1175 T_2=3357	T_1=157 T_2=448.8	T_1=671 T_2=2611	T_1=89.7 T_2=349.1	1.04-5.22	Analysis indicates probable change from semi-confined to unsaturated condition.
24	1	Pump	302*	--	--	T=112	T=15.0	.268	Analysis indicates probable change from semi-confined to unsaturated condition.
	2	Pump	302	--	--	T=278	T=37.2	.664	
	3	Injection	302	--	--	T=518	T=69.3	1.24	
25	NO AQUIFER TEST ON THIS ZONE IN THIS WELL.								
26	1	Pump	571*	T=71	T=9.5	--	--	.060	Zone almost completely drawn down in less than 5 minutes.
	2	Pump	571	T=103	T=13.8	--	--	.087	

NOTE: ALL AQUIFER TEST DATA AND TRANSMISSIVITY CALCULATIONS ARE CONTAINED IN THE NOSR 1 HYDROLOGY DATA BOOK, SECTION 2.6, TRW MARCH 1982.

*Approximate Static Water Level Prior to Beginning Test

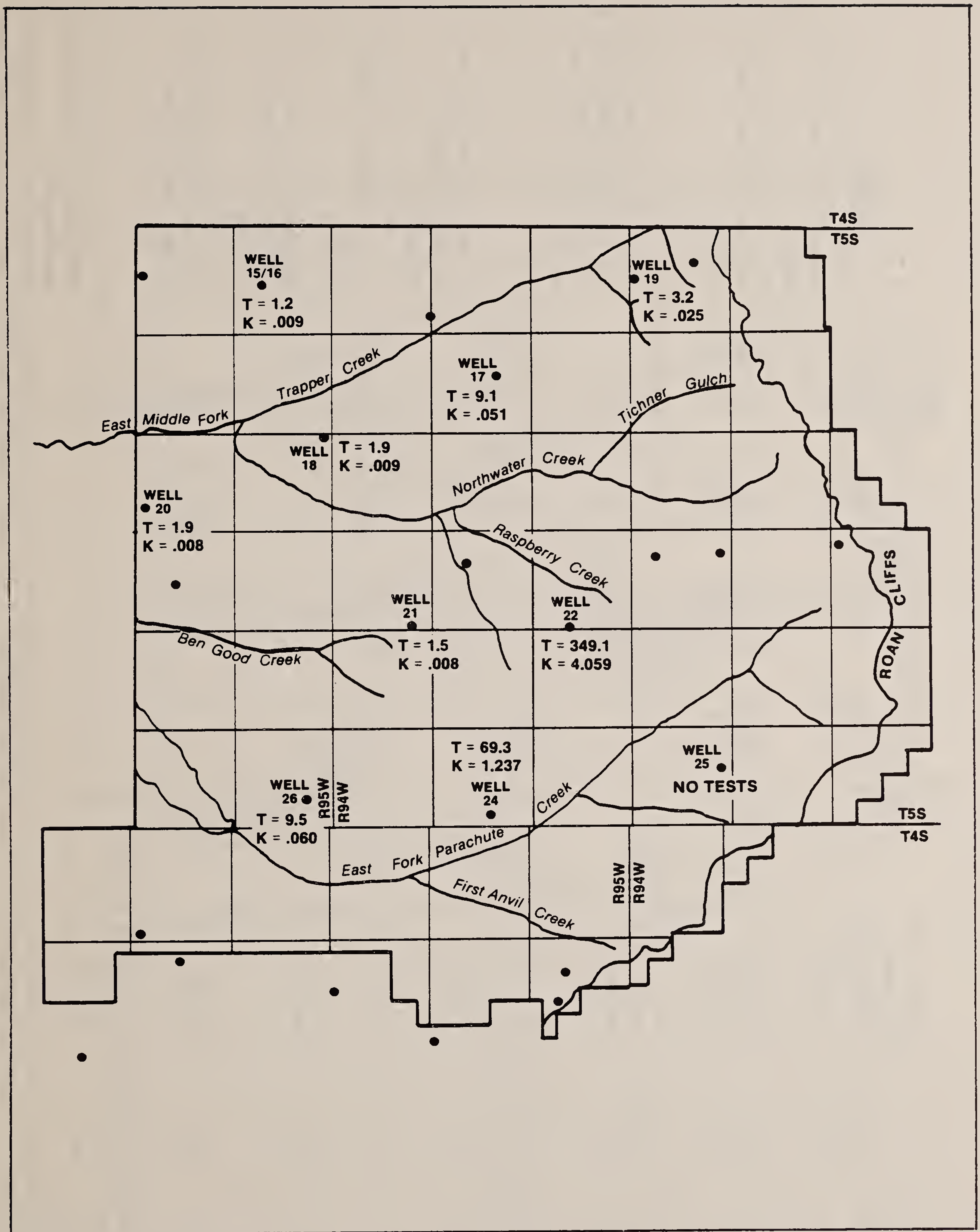


Figure 4-16. NOSR 1 Zone 1 Recovery Transmissivity (T in ft^2/day) and Hydraulic Conductivity (K in ft/day) Values. (Values plotted, unless otherwise noted, are taken from the portion of the Residual Recovery curve furthest into recovery.)

Table 4-20. NOSR 1, SUMMARY OF AQUIFER TESTS FOR ZONE 2

WELL NO.	WELL NO.	TEST TYPE	INTERVAL TESTED (Feet Below Ground Surface)	TRANSMISSIVITY, T — DRAWDOWN (gpd/ft)	TRANSMISSIVITY, T — DRAWDOWN (ft^2/day)	TRANSMISSIVITY, T — RECOVERY (gpd/ft)	TRANSMISSIVITY, T — RECOVERY (ft^2/day)	RANGE OF HYDRAULIC CONDUCTIVITY, K (ft/day)	REMARKS
15/16	1	Pump	1137-1253	T=163	T=21.8	T=137	T=18.3	.158-.188	Analysis indicates limited aquifer.
17	1	Pump	1074-1165	T=210	T=28.1	T=245	T=32.8	.309-.360	Analysis indicates limited aquifer.
	2	Pump	1074-1165	--	--	T_1=185 T_2=68	T_1=24.7 T_2=9.1	.100-.271	
18	1	Injection	735-957	--	--	T=42	T=5.6	.025	Test 2 pumping rate of 12 gpm may not have stressed zone sufficiently to give a good estimate of T.
	2	Pump	867-970			T=792	T=105.9	1.028	
19	NO AQUIFER TEST OF THIS ZONE IN THIS WELL.								
20	1	Pump	812-1061	--	--	T=352	T=47.1	.189	No water to surface. Zone completely drawn down in 90 seconds.
21	1	Pump	875-968	T=400	T=53.5	T=300	T=40.1	.431-.575	Analysis indicates limited aquifer.
22	1	Pump	688-790	--	--	--	--	--	No water to surface. Zone completely drawn down in 3 minutes.
24	1	Pump	513-610	--	--	T=7	T=.9	.009	Zone completely drawn down in less than 1 minute.
	2	Pump	513-610	--	--	T=11	T=1.5	.015	
25	NO AQUIFER TESTS ON THIS ZONE IN THIS WELL.								
26	1	Pump	742-900	--	--	--	--	--	Zone completely drawn down in 8 minutes.

NOTE: ALL AQUIFER TEST DATA AND TRANSMISSIVITY CALCULATIONS ARE CONTAINED IN THE NOSR 1 HYDROLOGY DATA BOOK, SECTION 2.6, TRW, MARCH 1982.

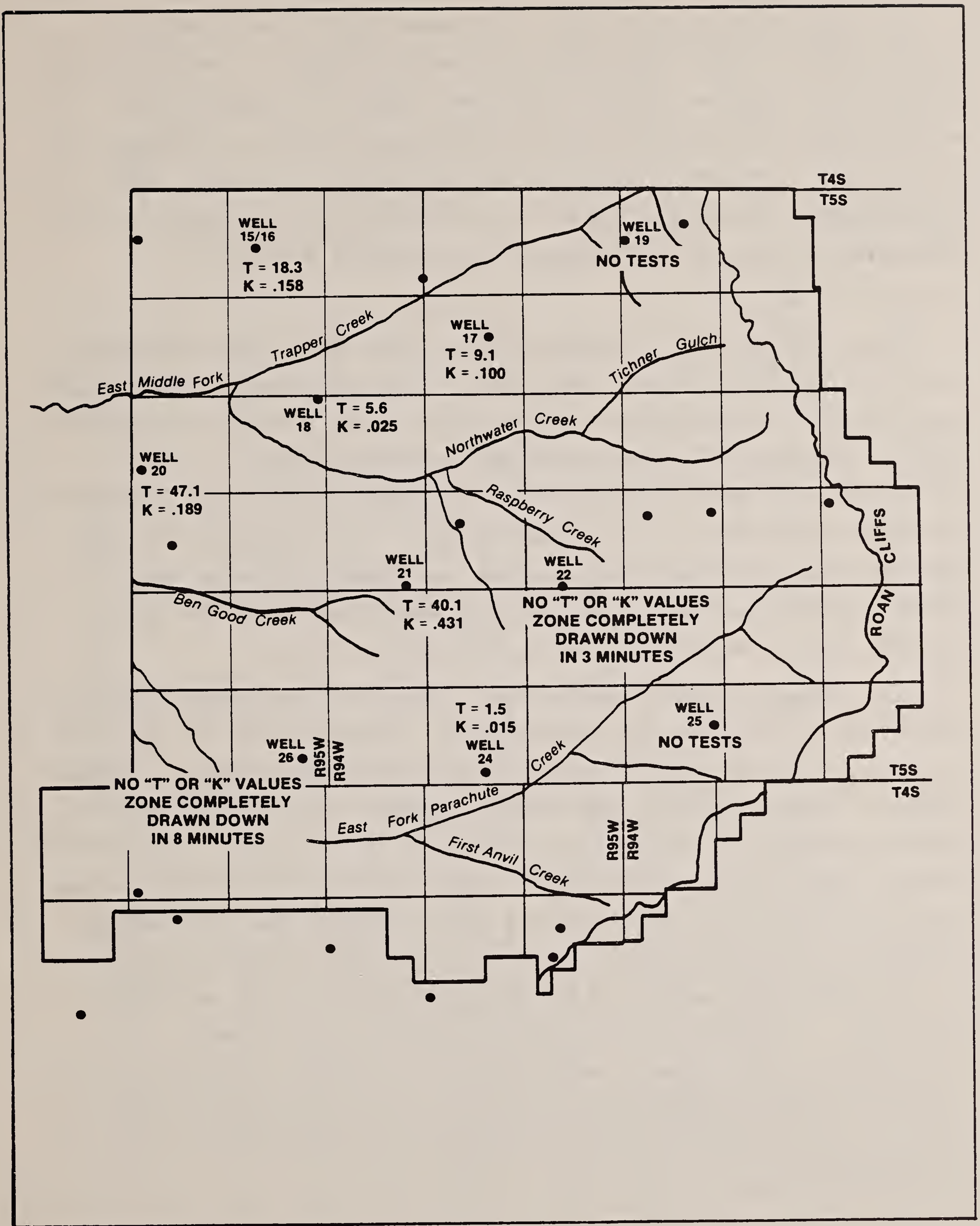


Figure 4-17. NOSR 1 Zone 2 Recovery Transmissivity (T in ft^2/day) and Hydraulic Conductivity (K in ft/day) Values. (Values plotted, unless otherwise noted, are taken from the portion of the Residual Recovery curve furthest into recovery.)

The "Remarks" column on Table 4-20 shows that recovery analysis indicates only limited productivity is present in Zone 2. The curves all indicated the negative boundary conditions common in fractured rocks. The areal pattern of the transmissivity and hydraulic conductivity values has no distinctive pattern, a pattern also often noted in fractured rocks. The largest hydraulic conductivity was calculated for Well 18, but this value is suspect because of the low pumping rate during the test.

4.3.2.3.3 Zone 3

Table 4-21 presents a summary of the aquifer test data obtained for Zone 3. Figure 4-18 presents representative aquifer parameter data on a map of NOSR 1. The calculated transmissivities and hydraulic conductivities are somewhat higher than those obtained from Zones 1, 2, and 4. As can be seen on Figure 4-18, the values are largest moving from southeast to northwest across NOSR 1. This zone represents the B-groove aquifer zone and its permeability may be enhanced by the presence of vuggy layers as a result of nahcolite dissolution, a factor which is also implied in the deterioration of water quality with depth at Well 15/16.

The slightly higher transmissivity values for Zone 3 were calculated from graphs of drawdown and recovery data. Except for Well 18, this zone is characterized by negative boundary conditions which indicate a limited aquifer. The test results from Well 18, however, show indications of a positive boundary during the first 100 minutes of the tests. This positive boundary condition may represent well-bore storage or may indicate strong leaky conditions. Well 18 is located near the end of the ridge between Northwater and Trapper Creeks, in an area which may be highly fractured. It is possible that because of fractures, all zones in this well are connected. In addition, Zone 3 may be connected to the streams. This connection to the streams is suggested by the fact that the Zone 3 potentiometric surface approximates the stream levels both north and south of Well 18 and because the reach on Trapper Creek directly north of the well is a losing reach.

Table 4-21. NOSR 1, SUMMARY OF AQUIFER TESTS FOR ZONE 3

WELL NO.	TEST NO.	TEST TYPE	INTERVAL TESTED (Feet Below Ground Surface)	TRANSMISSIVITY, T — DRAWDOWN (gpd/ft)	TRANSMISSIVITY, T — DRAWDOWN (ft^2/day)	TRANSMISSIVITY, T — RECOVERY (gpd/ft)	TRANSMISSIVITY, T — RECOVERY (ft^2/day)	RANGE HYDRAULIC CONDUCTIVITY, K (ft/day)	REMARKS
15/16	1	Pump	1239-1450	T_1=3960 T_2=660	T_1=529.4 T_2=88.2	--	--	.418-2.509	Analysis indicates limited aquifer.
17	1	Pump	1160-1459	T=1074	T=143.6	T_1=1150 T_2=619	T_1=153.7 T_2=82.8	.277-.514	
18	1	Injection	1000-1256(TD)	--	--	T_1=172 T_2=360	T_1=23.0 T_2=48.1	.089-.188	Analysis indicates leaky confining layer or interception by cone of depression of a fracture zone.
	2	Pump	966-1256 (TD)	T_1=189 T_2=914	T_1=25.3 T_2=122.2	T_1=198 T_2=475	T_1=26.5 T_2=63.5	.087-.421	
19	ZONE COMPLETELY DRAINED IN THIS WELL.								
20	1	Pump	1059-1300	T=502	T=67.1	T_1=304 T_2=1254	T_1=40.6 T_2=167.6	.168-.695	
21	1	Pump	966-1245	T_1=223 T_2=104	T_1=29.8 T_2=13.9	T=152	T=20.3	.050-.107	Analysis indicates limited aquifer.
22	1	Pump	928-1103	T_1=81 T_2=264	T_1=10.8 T_2=35.3	T_1=125 T_2=475	T_1=16.7 T_2=63.5	.062-.363	Analysis indicates limited aquifer.
24	1	Injection	653-939(TD)	--	--	T=303	T=40.5	.142	Analysis indicates limited aquifer.
	2	Pump	653-939(TD)	T=107	T=14.3	T=143	T=19.1	.050-.067	
	3	Pump	653-939(TD)	T=184	T=24.6	T=179	T=23.9	.083-.086	
25	1	Injection	675-925(TD)	--	--	T=49	T=6.6	.026	Analysis indicates limited aquifer.
26	1	Pump	902-1086(TD)	T_1=707 T_2=202	T_1=94.5 T_2=27.0	T_1=792 T_2=430	T_1=105.9 T_2=57.5	.147-.513	Analysis indicates limited aquifer.

NOTE: ALL AQUIFER TEST DATA AND TRANSMISSIVITY CALCULATIONS ARE CONTAINED IN THE NOSR 1 HYDROLOGY DATA BOOK, SECTION 2.6, TRW MARCH 1982.

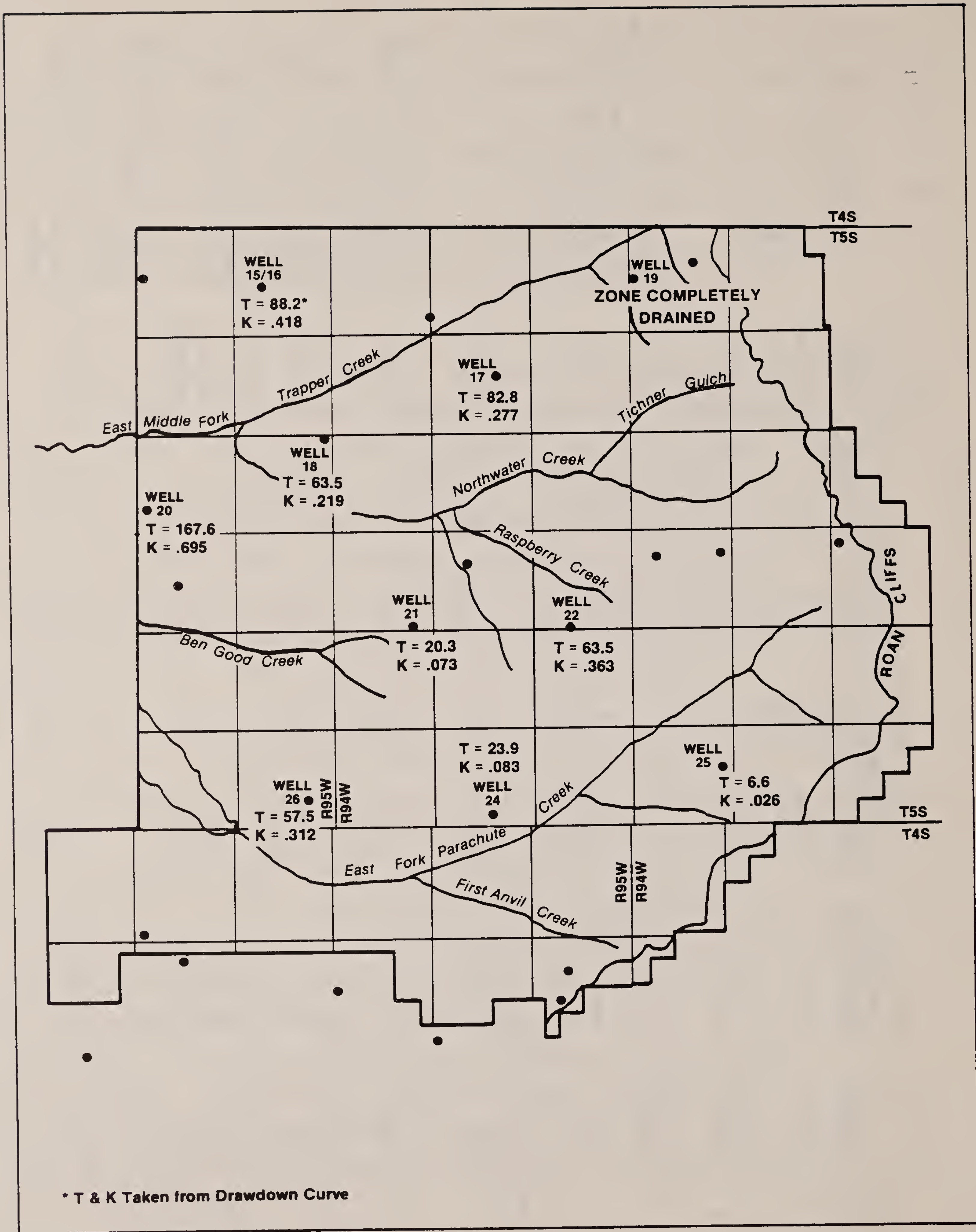


Figure 4-18. NOSR 1 Zone 3 Recovery Transmissivity (T in ft^2/day) and Hydraulic Conductivity (K in ft/day) Values. (Values plotted, unless otherwise noted, are taken from the portion of the Residual Recovery curve furthest into recovery.)

4.3.2.3.4 Zone 4

Table 4-22 presents a summary of the aquifer test data obtained for Zone 4. Representative aquifer data is shown in Figure 4-19. Aquifer tests were conducted at the five wells which penetrated this zone, and the tests all show low and variable values of transmissivity and hydraulic conductivity as observed in the other zones. The results are more scattered than those found in Zone 3 and do not display any pronounced trend.

The test results from one test at Well 20 indicate a positive response, indicating the possibility of a leaky confining layer. A combined test for Zones 3 and 4 also shows this same trend, indicating that the Mahogany zone may be fractured in this region and that leaky conditions exist between Zones 2, 3, and 4. The remaining tests in Zone 4 all display the fractured rock type response noted in the other zones. The graphical analyses indicate a limited aquifer and a negative boundary condition as the cone of depression grows.

4.3.2.4 Geohydrology

4.3.2.4.1 Recharge Characteristics

Recharge to the aquifer system on NOSR 1 occurs from two main sources. The primary source is from snowmelt. During the summer and fall months, most precipitation is lost to meet soil-moisture deficiency and is subsequently evapotranspired. Only a small percentage of the precipitation contributes to direct runoff. It is probable that none of the summer/fall precipitation percolates into the groundwater system. On the other hand, melting of the accumulated winter snowpack, which accounts for more than 60 percent of the total annual precipitation, results in saturation of the soil and percolation into the groundwater system. Water percolates slowly downward through vertical fractures, eventually recharging all four water-bearing zones on NOSR 1.

A second source of groundwater recharge is from isolated stream reaches where stream discharge measurements show a decrease in discharge in the downstream direction. On September 25-26, 1978 the U.S. Geological Survey took 63 instantaneous stream flow measurements along reaches of East Fork Parachute Creek, Ben Good Creek, and East Middle Fork Parachute Creek.

Table 4-22. NOSR 1, SUMMARY OF AQUIFER TESTS FOR ZONE 4

WELL NO.	TEST NO.	TEST TYPE	INTERVAL TESTED (Feet Below Ground Surface)	TRANSMISSIVITY, T: DRAWDOWN (gpd/ft)	DRAWDOWN (ft^2/day)	RECOVERY (gpd/ft)	RECOVERY (ft^2/day)	RANGE OF HYDRAULIC CONDUCTIVITY, K (ft/day)	REMARKS
15/16	1	Injection	1747-2019(TD)	--	--	T=6	T=.8	.003	Analysis indicates limited aquifer.
	2	Pump	1747-2019(TD)	--	--	T_1=9 T_2=10	T_1=1.2 T_2=1.3	.004-.005	
17	1	Pump	1428-1925(TD)	T=363	T=48.5	T_1=153 T_2=194	T_1=20.5 T_2=25.9	.041-.097	Analysis indicates limited aquifer.
20	1	Pump	1343-1920(TD)	T=71	T=9.5	T=118	T=15.8	.016-.027	Analysis indicates leaky confining layer or interception by cone of depression of a fracture zone.
	2	Pump	1343-1920(TD)	T_1=134 T_2=76 T_3=161	T_1=17.9 T_2=10.2 T_3=21.5	T_1=158 T_2=234	T_1=21.1 T_2=31.3	.018-.054	
21	1	Pump	1245-1650(TD)	T_1=190 T_2=35	T_1=25.4 T_2=4.7	T=176	T=23.5	.012-.063	Analysis indicates limited aquifer.
22	1	Pump	995-1577(TD)	--	--	T=14	T=1.9	.003	

NOTE: ALL AQUIFER TEST DATA AND TRANSMISSIVITY CALCULATIONS ARE CONTAINED IN THE NOSR 1 HYDROLOGY DATA BOOK, SECTION 2.6, TRW MARCH 1982.

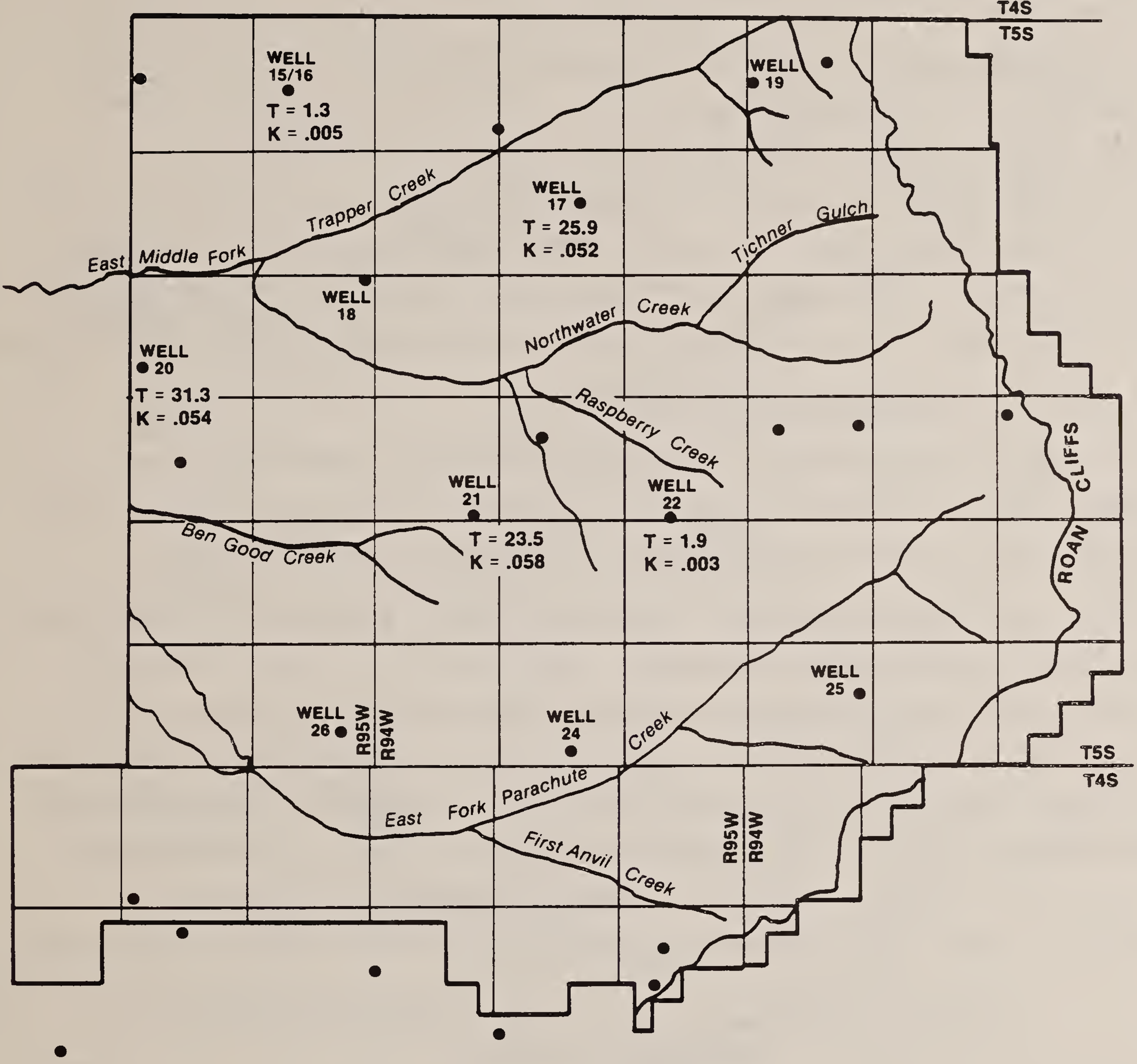


Figure 4-19. NOSR 1 Zone 4 Recovery Transmissivity (T in ft^2/day) and Hydraulic Conductivity (K in ft/day) Values. (Values plotted, unless otherwise noted, are taken from the portion of the Residual Recovery curve furthest into recovery.)

These measurements identified several reaches which show a significant decrease in discharge in the downstream direction. Figure 4-20 identifies these losing or recharge reaches. On East Fork Parachute Creek, the losing reaches generally correspond to stream-level outcropping of the Mahogany bed (see Figure 3-7). These losing reaches therefore contribute to the recharge of water-bearing Zones 3 and 4. On East Middle Fork Parachute Creek and its tributary Trapper Creek, the losing reach generally corresponds to outcrops of the Parachute Creek Member above the Wavey bed. This losing reach, therefore, contributes directly to recharge of water-bearing Zone 2. The potentiometric surface of Zone 3 in Well 18 indicates that this reach also contributes to recharge below the Mahogany bed.

4.3.2.4.2 Discharge Characteristics

On NOSR 1, groundwater is discharged from the upper three water-bearing zones by numerous springs. These springs contribute to base flow on East Fork Parachute Creek and East Middle Fork Parachute Creek.

As part of this hydrologic characterization, a detailed reconnaissance of springs on NOSR 1 was performed. Figure 4-21 is an index map which locates the springs visited during this reconnaissance. Data gathered included temperature, specific conductivity, pH, and estimated flow volume. Figure 4-22 shows representative temperatures and specific conductivities of springs on NOSR 1. Table 4-23 summarizes the specific conductivity values of all springs included in this reconnaissance. In addition, selected springs were sampled to provide representative water quality data.

Table 4-23. Summary of Specific Conductivity Values for NOSR 1 Springs

Number of Springs Sampled	Range of Specific Conductivities (μmhos/cm @ 25°C)	Mean Specific Conductivity (μmhos/cm @ 25°C)	Standard Deviation
90	340-695	516	69.64

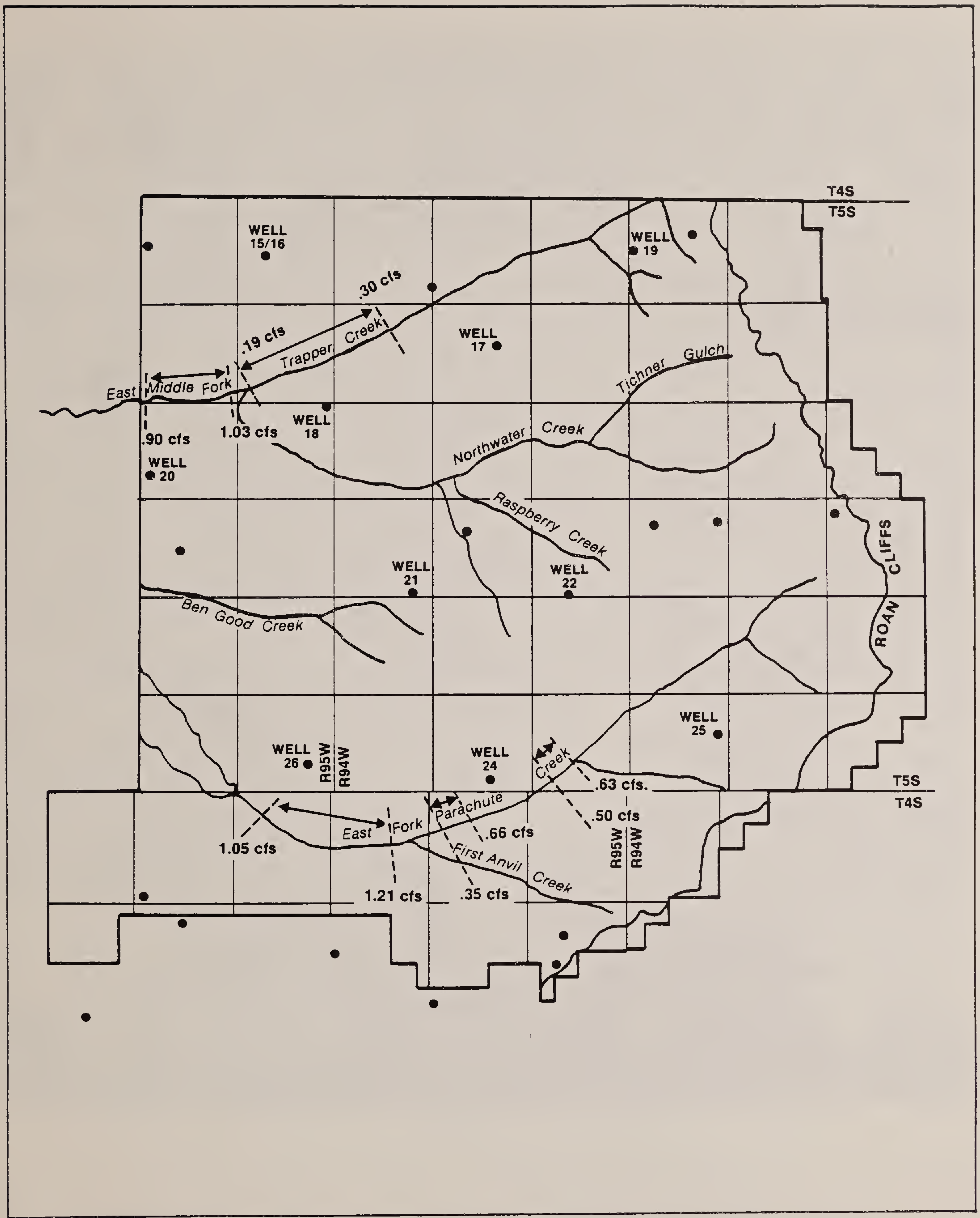


Figure 4-20. Isolated Stream Reaches on NOSR 1 Which Show a Decrease in Discharge in the Downstream Direction Based on USGS Instantaneous Stream Flow Measurements

Figure 4-21. Index Map, DOE/TRW Spring Reconnaissance Locations

Figure 4-22. Representative NOSR 1 Spring Temperature and Specific Conductivity Values

During the spring reconnaissance, an attempt was also made to identify the stratigraphic position of the springs. It was hoped that the springs would correlate with specific stratigraphic units which could be related to the water-bearing zones identified in the ten wells. It was further hoped that the water quality of the springs would be sufficiently different to allow identification of the water-bearing zone source for the individual springs. However, the field data gathered during the reconnaissance does not show sufficient differences to permit identification of discrete groundwater sources for individual springs.

4.3.2.4.3 Potentiometric Surfaces

Subsequent to aquifer testing, each of the ten wells on NOSR 1 was permanently completed to isolate the water-bearing zones. Since completion, the water level in each zone has been monitored on a monthly basis. Figure 4-23 summarizes the water levels measured in each well in February 1982. As indicated by the successively lower heads in the wells, water movement in the aquifers is generally downward. Downward movement of water occurs when the hydraulic head is lower in the underlying aquifer. However, there are two exceptions to this general trend.

In Well 18, the hydraulic head in Zone 3 is approximately 15 feet above the hydraulic head in Zone 2. Well 18 is located near the end of a ridge directly east of the confluence of Trapper and Northwater Creeks. Various data suggest that Zone 3 in this area is receiving direct recharge from the surrounding streams. Evidence for this includes:

- Positive boundary response during drawdown/recovery testing
- The reach on Trapper Creek directly north of Well 18 is a losing reach
- The potentiometric surface of Zone 3 is approximately at the same level as the surrounding streams

In addition, groundwater flow of the upper two water-bearing zones in this area is strongly influenced by local topography which allows direct discharge from these zones into the surrounding drainages. Therefore, the hydraulic head reversal between Zones 2 and 3 and the relatively close hydraulic heads of Zone 3 and Zone 1 (approximately 13 feet) may be indicative of localized draining of Zones 1 and 2 and direct recharge of Zone 3.

In Well 21, the hydraulic head in Zone 2 is approximately 40 feet above the hydraulic head in Zone 1. Again, local topography cuts down into Zone 1. This results in a localized reduction in the hydraulic head of Zone 1 leading to a reversal of the hydraulic gradient and potential for upward flow from Zone 2 to Zone 1.

In addition to indicating reversed gradient in Wells 18 and 21, Figure 4-23 also shows that the Zone 2 and 3 water levels in Wells 20 and 22 are the same. In Well 22, the cement plug was incorrectly placed. Therefore, Zones 2 and 3 are not effectively separated. In Well 20, the cement plug was correctly positioned. However, the identical water levels in Zones 2 and 3 indicate that the two zones were not effectively isolated. Possible reasons for this include:

- The cement may not have set due to the presence of gas in the formation at this well.
- Localized fracturing may connect Zones 2 and 3 in the vicinity of this well.

Figures 4-24 through 4-27 are potentiometric surface maps drawn from water levels measured in January 1982 for the four water-bearing zones on NOSR 1. The individual point measurements for each surface are shown on the maps.

The shape of the potentiometric surface for Zones 1, 2, and 3 indicate that flow is generally from east to west, and that East Fork Parachute Creek and the tributaries to East Middle Fork Parachute Creek act as linear discharge areas for these three zones.

The potentiometric maps indicate that topography, particularly the deeply incised steam valleys on and immediately west of the reserve, exerts a strong influence on the groundwater flow. The structural contours exhibit an east to northwest dip and probably are a minor contributor to the flow direction, certainly giving no resistance to the flow in response to the hydraulic gradient within each stratigraphic water bearing zone. The snowmelt recharge moves successively downward from Zone 1 through to Zone 4 with vertical fractures as the primary avenue of movement.

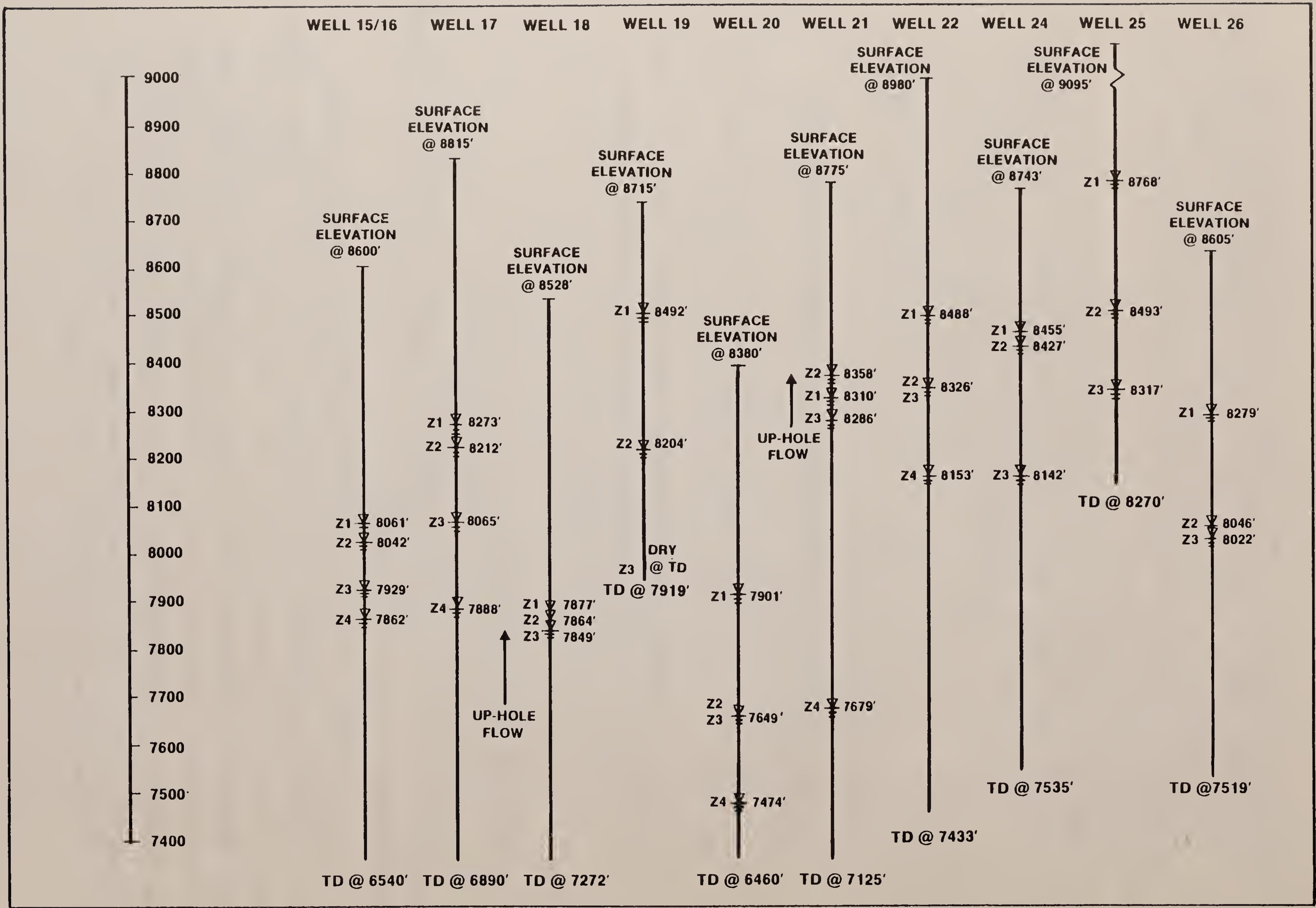


Figure 4-23. NOSR 1 Zone Water Levels, February 1982

Figure 4-24. NOSR 1 Zone 1, Potentiometric Surface Map

Figure 4-25. NOSR 1 Zone 2, Potentiometric Surface Map

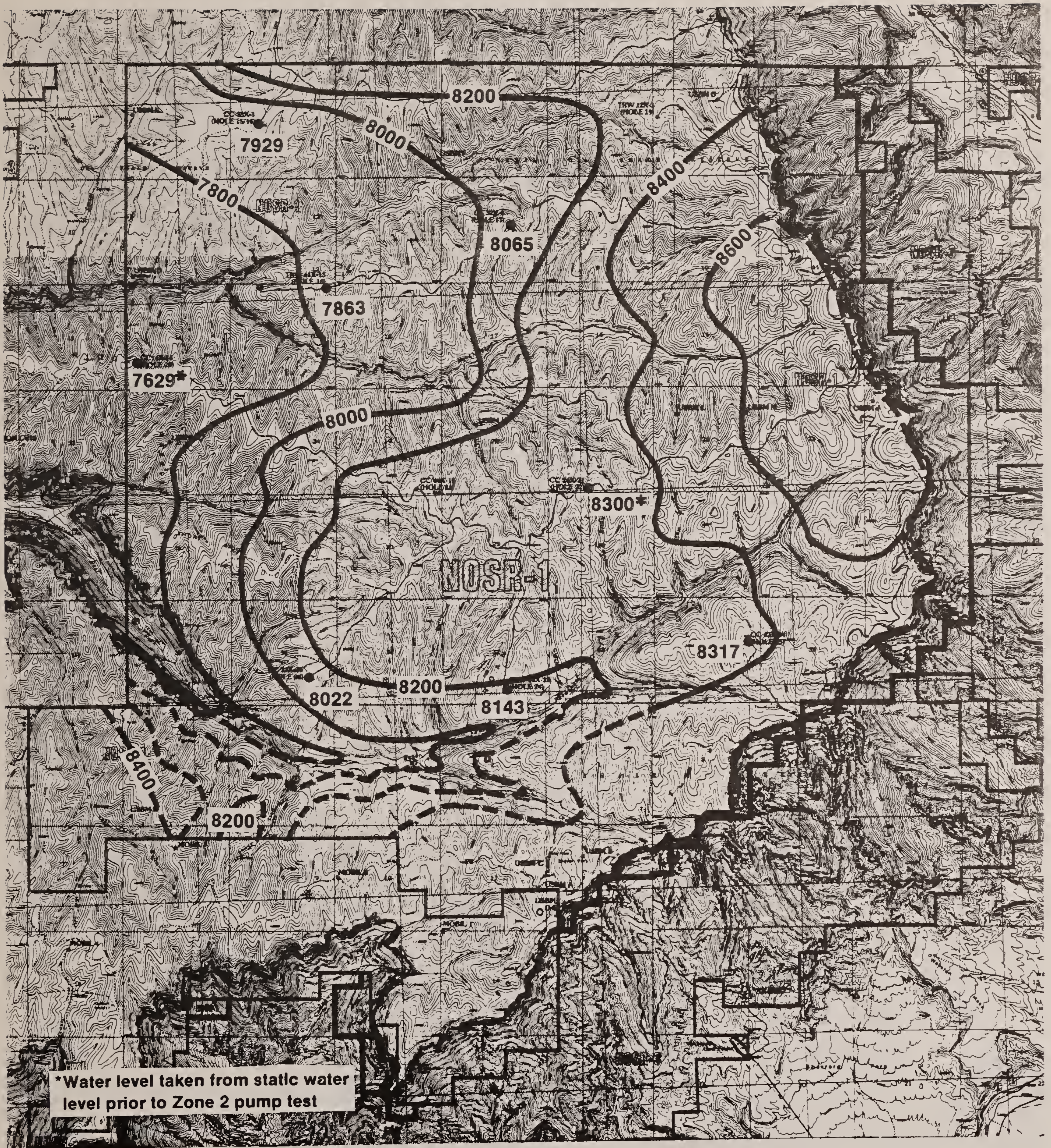


Figure 4-26. NOSR 1 Zone 3, Potentiometric Surface Map

Figure 4-27. NOSR 1 Zone 4, Potentiometric Surface Map

The total difference in hydraulic head from east to west on the reserve is about 1,000 feet in Zones 1 and 2, about 800 feet in Zone 3, and about 700 feet in Zone 4. The figures show that the gradients for each zone become lower moving vertically downward from Zone 1 to Zone 4 and that the steepest gradients in each zone lie along East Fork Parachute Creek. This variation in gradients is a result of increased vertical distance from recharge to discharge points, the decrease in total head within each zone, and a decrease in permeability with depth. The overall head relationships within each zone indicate the potential for flow is generally down from Zone 1 to Zone 4.

The individual piezometers have been measured regularly since mid-summer 1981 and periods of recovery from the previous open hole conditions have been from 1 to 6 months. As a result, any seasonal variations in water levels which may exist have not as yet been documented. The Zone 4 potentiometric surface has the same general form as the 3 zones above but the pattern is subdued and indicates some groundwater flow to the north toward Piceance Creek. There are fewer data points available to draw this surface, making inferences based on its shape less reliable. Nonetheless it is clear that even Zone 4 contributes to surface water discharge on NOSR 1.

4.3.2.5 Ground Water Quality

Groundwater quality on NOSR 1 was investigated, utilizing water samples obtained during the pump-aquifer testing described earlier in this section, and samples of water flowing from springs. The samples used to characterize the four water-bearing zones were collected during individual zone tests in which packers isolated the interval of interest. Care was taken to sample at the end of each test after many hole volumes had been removed from the test well, thus ensuring representative samples. The samples were analyzed by the Industrial Laboratory Company of Denver, Colorado, and all analyses were checked for chemical balance.

The drilling and testing of the NOSR 1 wells from 1977 to 1978 very often involved detection of hydrogen sulfide odor and indications of methane gas. Therefore, five of the dual-completed core-holes were capped by an assembly through which gas samples could be collected from above and below the packers. The analyses, as presented in Table 4-24, show only trace or extremely small amounts of methane and H_2S.

Table 4-24. Gas Analyses of Samples Obtained from NOSR 1 Monitor Wells

				MOL PERCENT							TRACE ANALYSIS VOLUME PPM (PARTS PER MILLION)								
WELL NUMBER	DATE ANALYZED	DATE COLLECTED	TIME COLLECTED	ARGON Ar	OXYGEN O_2	NITROGEN N_2	HYDROGEN H_2	CARBON DIOXIDE CO_2	METHANE C_1	PERCENT TOTAL	C_1	C_2	C_4	C_2+C_3	C_3+C_4	$(i-C_4)$ + $(n-C_4)$ + $(C_4$	$(i-C_5)$ + $(n-C_5)$ + $(C_5$	TOTAL SULFUR MICROGRAMS PER LITER g/l	H_2S CALCULATED PPM
15/16 UPPER	5/23/79	5/17/79	0805	1.0	14.6	82.1	ND*	0.1	2.2	100.0				9		3		1.9	1.7
	8/03/79	7/21/79	0905	0.8	21.1	78.1	ND	0.1	Tr**	100.0	3.0							0.4	0.4
15/16 LOWER	5/23/79	5/17/79	0800	1.0	15.4	83.5	ND	0.1	Tr	99.9	34							0.1	0.1
	8/03/79	7/21/79	0910	1.0	18.5	80.5	ND	Tr	Tr	100.0	3							0.3	0.3
17 UPPER	5/23/79	5/17/79	0935	0.9	19.1	79.8	ND	0.1	Tr	99.9	4	2						1.2	1.1
	8/03/79	7/21/79	1100	0.9	18.8	80.1	ND	0.2	Tr	100.0	2.0							2.0	1.8
17 LOWER	5/23/79	5/17/79	0940	0.9	18.6	80.4	ND	0.1	Tr	100.0	1	1						0.1	0.1
	8/03/79	7/21/79	1105	0.9	19.3	79.7	ND	0.1	Tr	99.9	3.0							0.2	0.2
18 UPPER	4/16/79	4/09/79	1240	1.3	6.7	91.5	ND	0.4	Tr	99.9	67			2	0.4			2.0	2.0
	9/03/79	7/21/79	1200	0.9	14.8	84.0	ND	0.3	Tr	100.0	8.0							4.1	3.7
18 LOWER	4/16/79	4/09/79	1235	1.1	16.0	82.3	ND	0.6	Tr	100.0	5			0.2				1.0	---
	8/03/79	7/21/79	1205	·0.9	17.1	82.0	ND	Tr	Tr	100.0	2.0							0.6	0.5
20 UPPER	4/16/79	4/09/79	1115	1.3	0.5	96.2	0.3	ND	1.6	99.9	16,010			13	5	4	7	1.0	---
	8/03/79	7/21/79	1755	1.1	7.4	90.7	ND	0.1	0.7	100.0	8,805							0.6	0.5
20 LOWER	4/16/79	4/09/79	1110	1.1	14.9	83.8	ND	0.1	Tr	99.9	278						15	1.0	1.0
	8/03/79	7/21/79	1800	0.8	18.7	80.4	ND	0.1	Tr	100.0	150							0.2	0.2
24 UPPER	4/16/79	4/09/79	1005	0.8	13.5	85.4	ND	0.1	0.1	99.9	1,004							1.0	1.0
	8/03/79	7/21/79	1350	0.6	15.6	83.2	ND	0.3	0.1	99.8	605							0.1	0.1
24 LOWER	4/16/79	4/09/79	1000	1.0	17.5	81.4	ND	ND	Tr	99.9	78							1.0	1.0
	8/03/79	7/21/79	1355	1.0	19.7	79.3	ND	Tr	Tr	100.0	65							0.1	0.1
ATMOSPHERE	HANDBOOK OF CHEMISTRY AND PHYSICS; 45TH EDITION			0.934	20.946	78.084	Tr	0.033	Tr	99.997	2								

* ND - NOT DETECTED
**Tr - TRACE

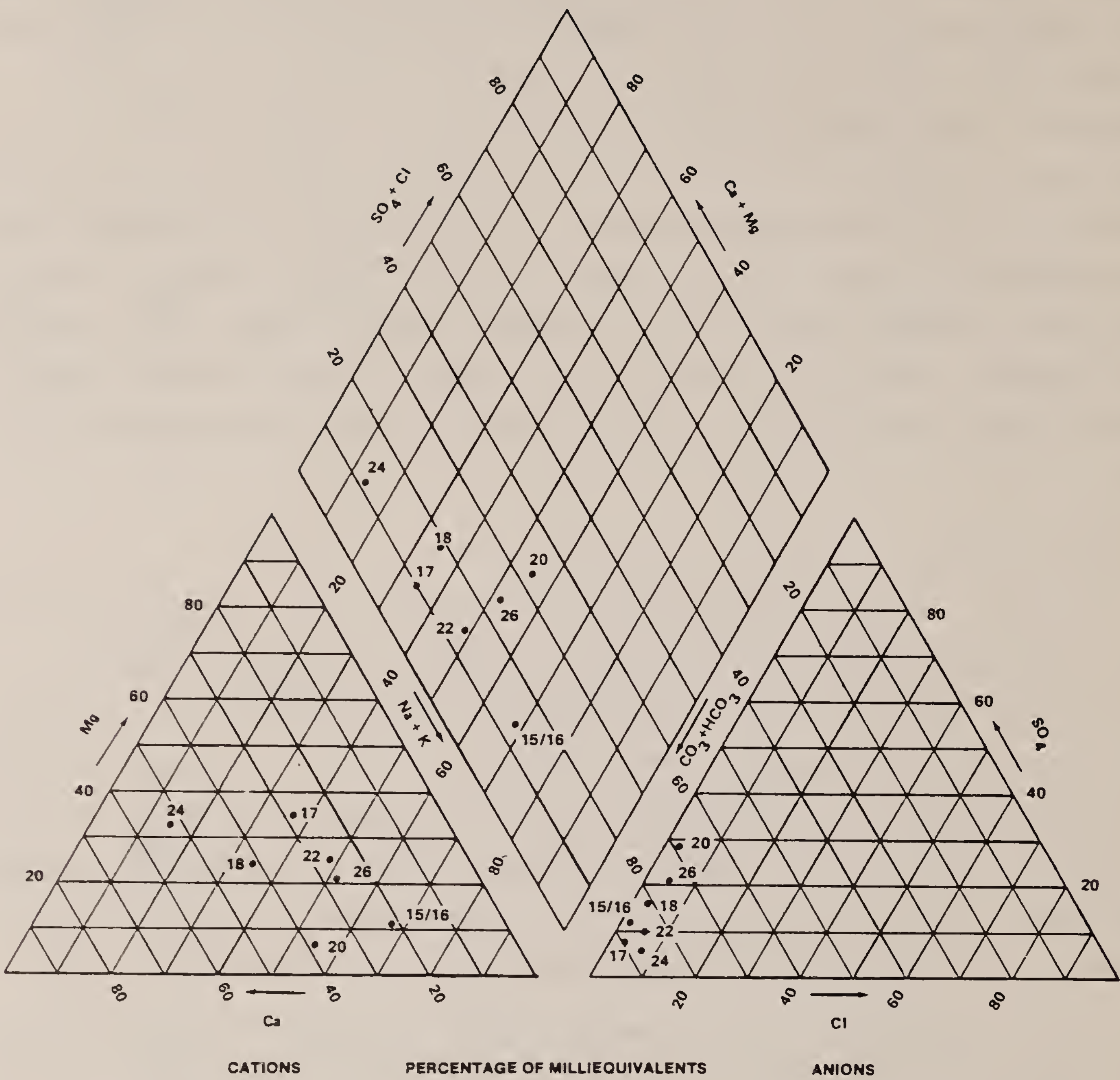
Combined with data showing lowered levels of dissolved oxygen, these analyses indicate that reducing conditions probably exist in some of the water bearing zones. The zones containing high amounts of organic material are the likely reduction zones. The reducing conditions may involve geochemical utilization of oxygen and sulfate in recharge waters, and organic and inorganic of sulfur in the oil shale, possibly aided by the presence of sulfur reducing bacteria. The presence of these conditions is also indicated by the corrosion noted on the metal pipe left in the core holes after the 1977 and 1978 field seasons and retrieved during the 1980 field season. Bacterial slime was also noted on pumps and pipes used in testing Zones 3 and 4 on Well 20, the test hole with the strongest H_2S odor.

4.3.2.5.1 Zone 1

The water quality in Zone 1 can be generally characterized as being low in dissolved solids concentration, having variable water types depending on geographic location, and possessing generally low concentrations of trace constituents. The analyses from Zone 1, with the exception of two from Well 21, are plotted on the piper diagram in Figure 4-28 and tabulated in Table 4-25. Well 21 analyses were not included because the tests were of very short duration and the water quality appeared to be indicative of borehole reactions rather than true formation quality.

Zone 1 groundwater can be classified as calcium-bicarbonate at Well 24, mixed-cation-bicarbonate at Wells 17, 18, and 22, and sodium bicarbonate at Wells 15/16, 20, and 26. When calcium-bicarbonate water is found in Piceance Creek basin, it is normally found in ground and surface waters in recharge areas (Saulnier, 1978). The Well 24 location correlates with the calcium carbonate surface water found at the East Fork Parachute Creek near Anvil Points gage, Section 4.3.1.4. Mixed-cation-bicarbonate water is the most common water type in recharge areas (Saulnier, 1978). This water type probably reflects contact of recharge with weathered rocks of the Uinta Formation and Upper Parachute Creek Member, and carbonate residues in the soil zone.

Groundwater moving slowly through water bearing Zone 1 changes character through calcite precipitation, ion exchange, and interactions with organic rich oil shales (Robson and Saulnier, 1981).



WELL NUMBER	TOTAL DISSOLVED SOLIDS mg/l
22	302
15/16	272
17	316
24	371
20	587
18	430
26	340

Figure 4-28. Piper Diagram of Chemical Analyses from NOSR 1 Zone 1.

Table 4-25. Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 1

Well	Calcium		Magnesium		Sodium		Potassium		Bicarbonate		Chloride		Sulfate		Fluoride
Number	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
22	26	1.30	15	1.23	55	2.39	3.7	0.09	255	4.18	9.1	.26	22	.46	0.1
15/16	18	.90	5.6	.46	70	3.04	4.0	.10	223	3.65	3.5	.10	24	.50	0.9
24	71	3.54	25	2.06	21	.91	4.0	.10	357	5.85	12	.34	22	.46	0.2
17	31	1.55	23	1.89	45	1.96	3.0	.08	267	4.38	4.9	.14	22	.46	0.4
21a	26	1.30	3.7	.30	85	3.70	3.7	.09	248	4.06	4.9	.14	27	.56	0.3
21b	23	1.148	19	1.564	114	4.959	1.3	.033	362	5.933	<3.0	.085	65	1.353	0.6
26	33	1.647	16	1.317	70	3.045	6.2	.159	280	4.589	13	.367	59	1.228	0.4
18	67	3.343	26	2.140	64	2.784	1.5	.038	395	6.474	8.5	.240	64	1.332	0.1
20	82	4.092	5.8	0.477	132	5.742'	1.3	.033	438	7.179	<3.0	.085	145	3.019	1.6

Well Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
22	5.019	4.894	+.0126	2.12	302	460
15/16	4.506	4.687	-.0197	3.69	272	480
24	6.616	6.648	-.0024	0.54	371	660
17	5.474	5.406	+.0062	1.49	316	570
21a	5.39	5.23	+.0149	4.13	313	610
21b	7.704	7.371	+.0221	4.6	430	855
26	6.167	6.184	-.0014	2.5	340	670
18	8.305	8.046	+.0158	1.7	430	650
20	10.344	10.282	+.0030	3.9	587	1000

Abbreviations Explanation

mg/l = milligrams per liter
meq/l = milliequivalents per liter
SAR = sodium adsorption ratio

$$\text{Balance} = \frac{\text{Sum cations} - \text{sum anions}}{\text{Sum cations} + \text{sum anions}}$$

TDS = Total dissolved solids

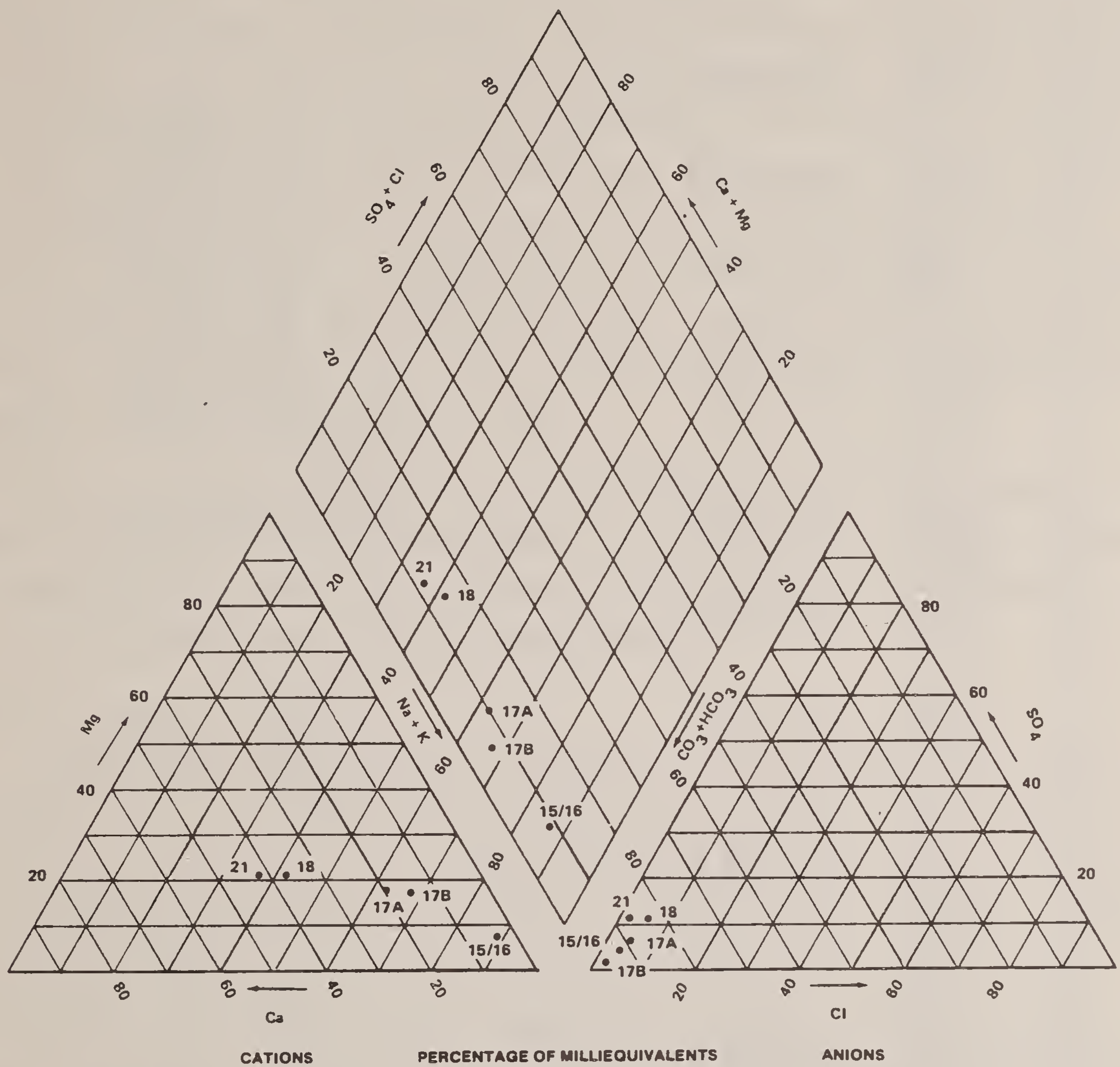
Reference to the potentiometric maps in Section 4.3.2.4.3 shows that Wells 15/16, 20, and 26, all lie far enough down-gradient from areas of recharge to give Zone 1 groundwater an opportunity to change from mixed-cation to sodium bicarbonate. The lower dissolved solids concentration noted at Well 15/16 indicates that removal of calcium through precipitation of calcite was the dominant process along this flow path. Well 20 shows an increase in dissolved solids and a shift to higher sulfate concentrations. This indicates probable interaction with pyrite bearing marlstones, and probable contact with organic material in oil shale. These processes lead to more sodic water through ion exchange and higher amounts of sulfate from sulfide oxidation. The fact that the analysis shows high calcium and low magnesium is a possible indication that calcium bearing soluble minerals may be present in the weathered zone in this area.

The dissolved solids concentrations and the specific conductance values, indicate that for the Zone 1, all but the sample from Well 20 satisfy federal drinking water standards and that Zone 1 water is safe for agricultural use. In the sample from Well 20, dissolved iron is high at 5.8 mg/l, dissolved fluoride is elevated at 1.6 mg/l, and the specific conductance is 1000 micromhos/cm.

4.3.2.5.2 Zone 2

Zone 2 is represented by 5 samples tabulated in Table 4-26 and illustrated on the Piper diagram, Figure 4-29. Zone 2 contains either mixed-cation-bicarbonate water or sodium-bicarbonate water. The highest concentration of dissolved solids is found in Well 15/16 and the lowest in Well 21. Among trace constituents, only fluoride was found in significant concentrations with values ranging from 0.3 mg/l at hole 18, to 3.5 mg/l at Well 15/16.

The few analyses available from this zone make detailed interpretations difficult. However, a few general indications can be observed. The water appears to change in quality moving from south to north. Water from Wells 15/16 and 17 has more sodium and fluoride and dissolved solids than does the water at Wells 18 and 21. In Piceance Creek basin, this water type is indicative of longer formation residence time, implying that Wells 15/16 and 17 may be further from recharge areas than Wells 18 and 21.



WELL NUMBER	TOTAL DISSOLVED SOLIDS mg/l
15/16	520
17A	346
21	300
18	345
17B	386

Figure 4-29. Piper Diagram of Chemical Analyses from NOSR 1 Zone 2.

Table 4-26. Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 2.

Well	Calcium		Magnesium		Sodium		Potassium		Bicarbonate		Chloride		Sulfate		Fluoride
Number	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
15/16	4.9	.24	8.7	.72	180	7.83	6.3	.16	497	8.15	11	.31	23	.48	3.5
17a	25	1.25	13	1.07	80	3.48	4.7	.12	331	5.42	8.4	.24	15	.31	1.9
17b	20	.998	14	1.152	98	4.263	3.0	.077	376	6.163	9.1	.256	<4.0	.083	3.1
21	49	2.445	15	1.234	48	2.088	<1.0	.026	312	5.114	<3.0	.085	30	.625	0.5
18	52	2.595	17	1.399	65	2.828	0.6	.015	345	5.655	13	.367	32	.666	0.3

Well Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
15/16	8.950	8.935	+.0008	11.30	520	828
17a	5.917	5.974	-.0048	3.23	346	570
17b	6.490	6.503	-.0010	2.0	386	627
21	5.793	5.824	-.0027	1.5	300	545
18	6.837	6.688	+.0111	2.0	345	555

Abbreviations Explanation

mg/l = milligrams per liter
meq/l = milliequivalents per liter
SAR = sodium adsorption ratio

$$\text{Balance} = \frac{\text{Sum cations} - \text{sum anions}}{\text{Sum cations} + \text{sum anions}}$$

TDS = Total dissolved solids

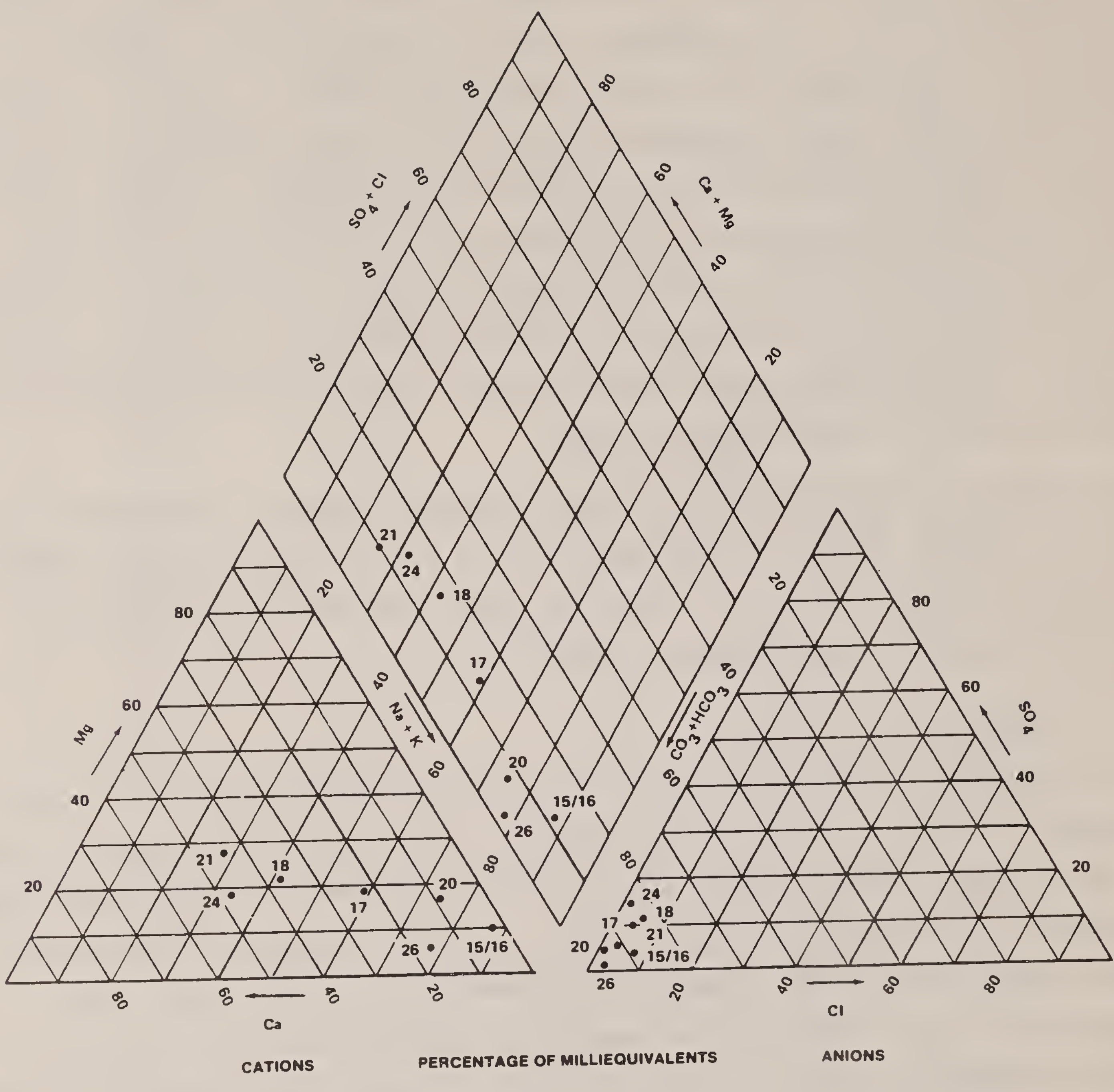
Changes in water type in Zone 2 involve increases in dissolved solids greater than observed in Zone 1. Possible processes that could be at work are sulfate reduction, ion exchange, calcite precipitation, and nahcolite dissolution. While nahcolite is not prevalent on NOSR 1, some occurrances are observed in oil shale properties to the west. The increase in fluoride definitely indicates some mineral dissolution or exchange, and the lowered calcium concentration allows the fluoride to stay in solution. Sulfate reduction in the presence of organic material leads to increases in carbonate species in solution, presence of hydrogen sulfide, and secondary pyrite formation. All three have been noted in Zone 2 during drilling operations (Saulnier, written communication, 1978).

The water in Zone 2 does not exceed drinking water or agricultural use standards at Wells 18 and 21, but Wells 15/16 and 17 have a medium sodium and salinity hazard, and exceed drinking water standards for dissolved solids (Well 15/16), and fluoride (both wells).

4.3.2.5.3 Zone 3

Seven analyses are available to characterize the chemical character of groundwater in Zone 3. Two of the analyses are from Well 20. Samples from Wells 18, 21, and 24 have mixed cation-bicarbonate water and the remaining two samples are sodium-bicarbonate water. Figure 4-30 is a Piper diagram for these analyses and the results are summarized in Table 4-27. The concentration of dissolved solids ranges from 290 mg/l at Well 21, to 490 mg/l at Well 20. Fluoride concentration exceeds 1 mg/l for five of the samples and ranges from 0.2 mg/l at Well 24, to 5 mg/l at Well 26.

Zone 3 water has its least dissolved solids concentration and its most intermediate water type in the central part of NOSR, indicating that recharge to this zone may occur in this region. As groundwater moves away from the recharge area, chemical reactions such as mineral dissolution, sulfur reduction, mineral precipitation, and ion exchange alter the composition to form a sodium-bicarbonate water. The effect of these reactions is more pronounced as flow path length and residence time increases. Thus Well 20 has the highest concentration of dissolved solids and is observed to evolve hydrogen sulfide and methane gas, both products of organic and inorganic sulfur and carbon reduction. The sulfur is either present with



WELL NUMBER	TOTAL DISSOLVED SOLIDS mg/l
18	355
26	400
20	490
24	420
21	290
17	296
15/16	470

Figure 4-30. Piper Diagram of Chemical Analyses from NOSR 1 Zone 3.

Table 4-27. Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 3.

Well	Calcium		Magnesium		Sodium		Potassium		Bicarbonate		Chloride		Sulfate		Fluoride
Number	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
18	51	2.545	18	1.481	63	2.741	0.1	.003	345	5.655	9.8	.276	38	.791	0.3
26	23	1.148	4.4	.362	125	5.438	3.0	.077	414	6.785	5.6	.158	<4.0	.083	5.0
20	15	.749	18	1.481	150	6.525	8.4	.215	500	8.195	11	.310	22	.458	2.5
24	71	3.54	16	1.32	55	2.39	4.0	.10	382	6.26	<3.0	<.08	48	1.0	0.2
21	46	2.30	17	1.40	30	1.31	3.0	.08	287	4.70	4.9	.14	17	.35	0.6
17	25	1.25	12	0.99	70	3.05	3.7	.09	248	4.06	4.9	.14	25	.52	1.6
15/16	4.9	.24	9.8	.81	160	6.96	4.7	.12	446	7.31	15	.42	20	.42	2.8

Well Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
18	6.769	6.722	+.0035	1.9	355	550
26	7.024	7.026	-.0002	6.26	400	649
20	8.97	8.963	+.0004	6.2	490	785
24	7.354	7.345	+.0006	1.53	420	671
21	5.076	5.196	-.0117	0.96	290	495
17	5.37	5.357	+.0012	2.88	296	556
15/16	8.131	8.149	-.0011	9.61	470	759

Abbreviations
Explanation

mg/l = milligrams per liter
meq/l = milliequivalents per liter
SAR = sodium adsorption ratio

$$\text{Balance} = \frac{\text{Sum cations} - \text{sum anions}}{\text{Sum cations} + \text{sum anions}}$$

TDS = Total dissolved solids

the hydrocarbons or as iron sulfide in the oil shale. Observations in the northern Piceance Creek basin support this general mechanism of geochemical change (Robson and Saulnier, 1981).

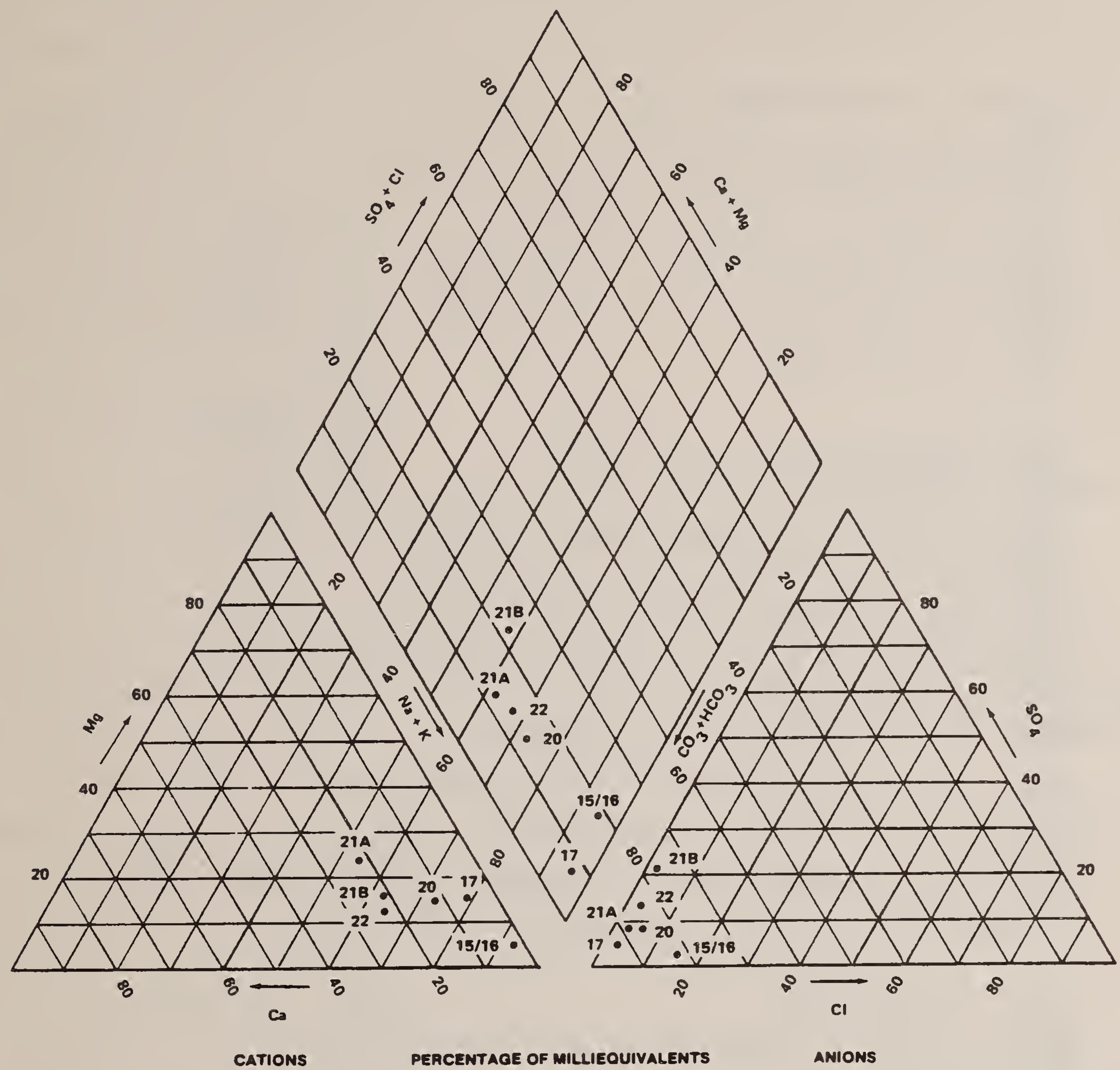
Elevated fluoride concentrations in the down-gradient wells suggests either an evaporitic or tuffaceous source of fluoride. Both lithologies can release fluoride to circulating groundwater, and a lowered calcium level due to calcite precipitation and ion exchange reactions helps keep the fluoride levels up. Large amounts of evaporites are not reported on NOSR 1 but are known to exist in nodular layers concentrated along bedding planes in the Mahogany zone to the west and northwest. If minor amounts are present on NOSR 1, the observed sodium bicarbonate and fluoride increases can be more easily explained.

Zone 3 water has a medium salinity and low sodium hazard in the down-gradient wells. Dissolved solids concentrations meet EPA drinking water standards at all wells, but the fluoride concentration exceeds the EPA Standards at Wells 15/16, 17, 20, and 26.

4.3.2.5.4 Zone 4

Six water analyses are available for Zone 4 and two of these are from Well 21. The analytical results are summarized in Table 4-28 and graphically represented in Figure 4-31. All the groundwater in Zone 4 can be classed as a sodium-bicarbonate water. The least sodium content and lowest dissolved solids concentration are found at Well 21. All wells, except 20, have elevated levels of fluoride with the maximum found at Well 15/16 (7 mg/l). Most wells have low iron concentrations but 2 mg/l is reported for Well 22.

Zone 4 follows a pattern similar to that found in the zones above. Water quality becomes dominated by sodium and bicarbonate moving and laterally north and west from the central portions of the Reserve. In contrast to Zones 1 and 2, there is a more pronounced net increase in the amount of sodium and TDS in Zones 4 and a significant depression of calcium concentration especially in the down-gradient wells. The chloride and sodium concentrations in Well 15/16 are the highest recorded on NOSR 1, indicating the possibility of some evaporite mineral dissolution either on the northern border of the reserve or in the region immediately north



WELL NUMBER	TOTAL DISSOLVED SOLIDS mg/l
15/16	1060
17	415
21a	318
21b	381
20	519
22	450

Figure 4-31. Piper Diagram of Chemical Analyses from NOSR 1 Zone 4.

Table 4-28. Summary of Analytical Results for Major Ions and Selected Parameters for Groundwater Samples from NOSR 1 Zone 4.

Well	Calcium		Magnesium		Sodium		Potassium		Bicarbonate		Chloride		Sulfate		Fluoride
Number	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l
15/16	6.6	.33	6.6	.54	410	17.84	20	.51	910	14.91	106	2.99	20	.42	7.0
17	9.8	.49	13	1.07	130	5.66	4.0	.10	414	6.79	4.9	.14	20	.42	2.6
21a	25	1.25	12	.99	80	3.48	3.3	.08	312	5.11	6.3	.18	23	.48	2.3
21b	30	1.497	20	1.646	85	3.698	1.3	.033	333	5.458	<3.0	.085	68	1.416	1.6
20	20	.998	19	1.564	155	6.743	1.3	.033	497	8.146	12	.339	40	.833	2.8
22	39	1.946	13	1.070	125	5.438	<1.0	.026	435	7.130	9.2	.260	50	1.041	0.3

Well Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
15/16	19.219	18.95	+.0069	27.05	1060	1820
17	7.32	7.34	-.0014	6.41	415	682
21a	5.80	5.77	+.0026	3.29	318	528
21b	6.874	6.958	-.0061	2.9	381	707
20	9.337	9.317	+.0011	6.0	519	1030
22	8.479	8.430	+.0029	5.1	450	<0.2

Abbreviations

Explanation

mg/l = milligrams per liter

meq/l = milliequivalents per liter

SAR = sodium adsorption ratio

$$\text{Balance} = \frac{\text{Sum cations} - \text{sum anions}}{\text{Sum cations} + \text{sum anions}}$$

TDS = Total dissolved solids

towards Piceance Creek. The high concentration of fluoride at Well 15/16 also reflects the possibility of increased dissolution, as does the dissolved solids concentration.

A medium salinity hazard exists for Zone 4 water from all wells and a high salinity hazard is found at Wells 15/16 and 20. The sodium hazard is generally low but a medium hazard is found at Well 20 and a very high sodium hazard is indicated for Well 15/16. Wells 15/16 and 20 exceed EPA drinking water standards for dissolved solids and all wells, except 22, exceed the fluoride standard.

4.3.2.5.5 Vertical Variation

Figure 4-32 illustrates the vertical variation of the water between aquifer zones on NOSR 1. The graph presents analyses from the down-gradient Wells 15/16 and 17. With increasing depth, each well shows an increase in dissolved solids concentration and a shift to a dominantly sodium-bicarbonate character. Zones 2 and 3 are quite similar but Zones 1 and 4 are quite dissimilar. The mechanisms responsible for this change are long residence time allowing the water to attack the host rock, ion exchange of calcium for sodium from clays and feldspars, calcite precipitation removing calcium, sulfur reduction in the presence of organic material, and dissolution of evaporite minerals such as nahcolite and possibly halite.

Water in the southeast-central portion of NOSR 1 is more uniform vertically. This area is in the recharge portion of the basin and, because of the weathered condition of the rock and the thin soil cover, the infiltrating water which enters the water-bearing zones has a relatively high concentration of dissolved solids close to the recharge area. This initial slug of solute is dominated by the soluble mineralogy of the marlstones and carbonate cemented siltstones of the Green River and Uinta Formations. The circulating groundwater is then either discharged locally as springflow, much of which is seasonal on NOSR 1, or remains in the rock system to undergo the changes discussed above.

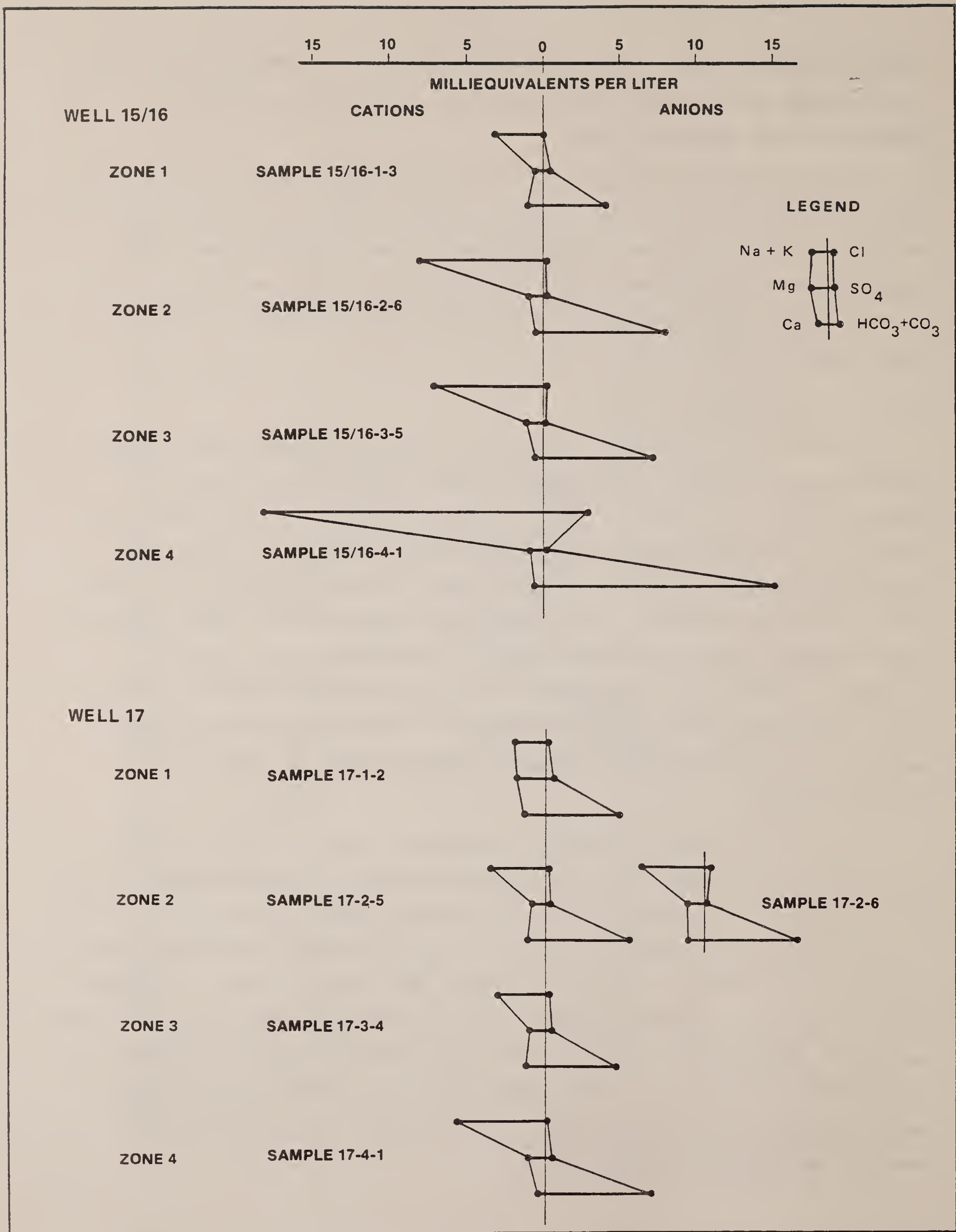


Figure 4-32. Stiff Patterns for Wells 15/16 and 17 Showing Increase in Dissolved Solids and Change in Ionic Character of Ground Water with Increasing Depth

4.3.2.5.6 Quality of Spring Water

Samples from springs on NOSR 1 were collected during the 1980 and 1981 field seasons. These analyses are summarized in Tables 4-29 and 4-30, and plotted on the Piper diagrams in Figures 4-33 and 4-34.

The analyzes indicate that the spring water on NOSR 1 is quite uniform. All the analyses are either calcium-bicarbonate type waters or mixed-cation-bicarbonate waters with calcium the dominant cation. As can be seen on Figure 4-33, many of the analyses fall in a small field on the Piper plot and have a narrow range of total dissolved solids. None of the sample analyses have significant concentrations of trace constituents, and fluoride concentrations are extremely low. The results show that all spring waters meet EPA drinking water standards and all have a low sodium and medium salinity hazard.

Figure 4-34 illustrates the analyses of three springs from apparently different stratigraphic intervals in East Fork Parachute Creek. These samples were collected from strata which were part of Zone 1, (Spring 30); Zone 2, (Spring 31); and Zone 3, (Spring 32). The "A" samples were sampled in September 1980, the "B" samples in February 1981, and the "C" samples in July 1981. Examination of the analyses and the information in Figure 4-34, reveals that the September samples display a higher percentage and total concentration of calcium, and an overall slightly higher concentration of dissolved solids. These analyses are also much different from the ground-water samples presented above for the different zones. The samples probably represent the last through-put of water recharged during snowmelt. Evapotranspiration processes probably operate deep through the soil zone and have contributed to enriching the water in calcium. This late season effect is probably responsible for the travertine coatings noted on the surface near these springs. The fact that all three springs appear together when plotted on the Piper Diagram also indicates again that most of the spring systems on the southeast part of NOSR 1 are near surface phenomena and do not reflect discharge from the regional flow systems.

Table 4-29. Summary of Analytical Results for Major Ions and Selected Parameters for Spring Samples Collected NOSR 1

Spring Number	Date Sampled	Calcium mg/l	Calcium meq/l	Magnesium mg/l	Magnesium meq/l	Sodium mg/l	Sodium meq/l	Potassium mg/l	Potassium meq/l	Bicarbonate mg/l	Bicarbonate meq/l	Chloride mg/l	Chloride meq/l	Sulfate mg/l	Sulfate meq/l	Fluoride mg/l	Strontium mg/l
2	7/28/81	61	3.044	19	1.564	41	1.784	<1.0	.026	310	5.081	6.4	.181	53	1.103	<.1	0.1
26	7/28/81	72	3.593	24	1.975	48	2.088	<1.0	.026	390	6.392	11	.310	49	1.020	<.1	0.2
33	7/29/81	66	3.293	15	1.234	37	1.610	<1.0	.026	295	4.835	11	.310	48	.999	<.1	0.1
43	6/17/81	46	2.295	17	1.399	31	1.349	2.4	.061	245	4.016	12	.339	37	.770	0.8	--
46	6/18/81	54	2.695	20	1.646	25	1.088	2.6	.067	245	4.016	23	.649	39	.812	0.8	--
53	7/24/81	66	3.293	16	1.316	30	1.305	<1.0	.026	310	5.081	5.6	.158	33	.687	<.1	0.1
78	9/1/81	59	2.944	19	1.563	47	2.045	2.5	.064	300	4.917	7.1	.200	62	1.291	0.1	--
84	9/2/81	62	3.094	20	1.646	39	1.697	2.8	.072	335	5.491	11	.310	25	.521	0.1	--
87	9/3/81	54	2.695	19	1.563	44	1.914	2.7	.069	310	5.081	20	.564	29	.603	0.1	--

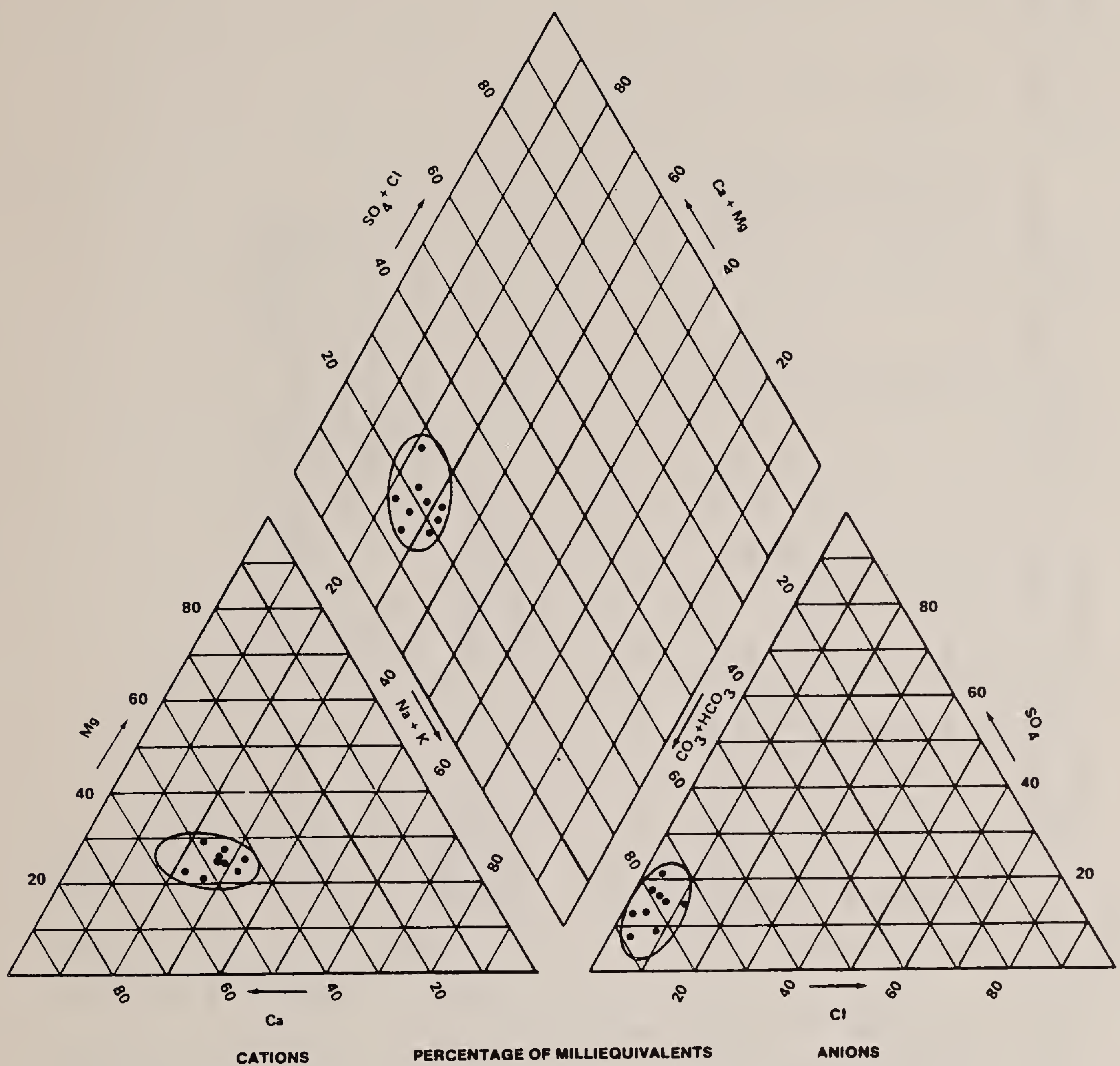
Spring Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
2	6.365	6.417	+.0041	1.18	340	520
26	7.723	7.681	-.0027	1.25	400	665
33	6.145	6.163	+.0015	1.07	330	480
43	5.104	5.124	-.0019	0.99	315	450
46	5.494	5.477	+.0016	0.74	280	490
53	5.926	5.941	-.0010	0.86	330	505
78	6.408	6.616	+.0160	1.36	350	540
84	6.321	6.508	+.0145	1.10	340	520
87	6.249	6.241	-.0006	1.31	320	520

Abbreviations
Explanation

mg/l = milligrams per liter
meq/l = milliequivalents per liter
SAR = sodium absorption ration

$$\text{Balance} = \frac{\text{Sum cations} - \text{sum anions}}{\text{Sum cations} + \text{sum anions}}$$

TDS = Total dissolved solids



SPRING NUMBER	TOTAL DISSOLVED SOLIDS mg/l
53	330
26	400
2	340
33	330
84	340
78	350
87	320
43	315
46	280

Figure 4-33. Piper Diagram of Chemical Analyses from Springs on NOSR 1.

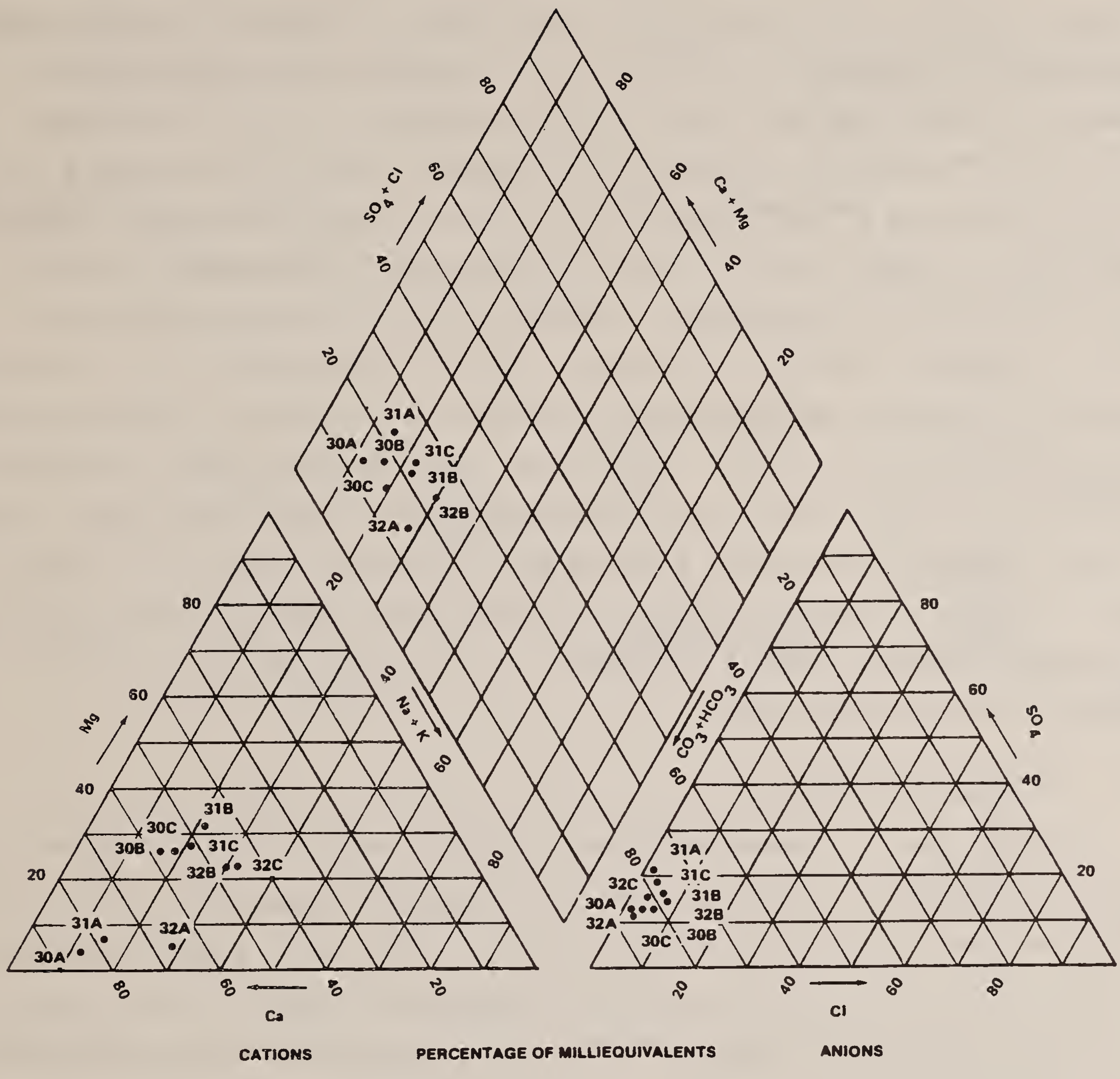
Table 4-30. Summary of Analytical Results for Major Ions and Selected Parameters for Three Selected NOSR 1 Springs - Each Spring was Samples Several Times to Document Seasonal Variation of Water Quality

Spring Number	Date Sampled	Calcium mg/l	Calcium meq/l	Magnesium mg/l	Magnesium meq/l	Sodium mg/l	Sodium meq/l	Potassium mg/l	Potassium meq/l	Bicarbonate mg/l	Bicarbonate meq/l	Chloride mg/l	Chloride meq/l	Sulfate mg/l	Sulfate meq/l	Fluoride mg/l	Strontium mg/l
30A	9/21/80	113	5.639	3.2	0.263	17	0.740	1.0	.026	351	5.753	3.0	.085	43	.895	.1	--
30B	3/26/81	78	3.892	21	1.728	27	1.175	<1.0	.026	340	5.573	16	.451	37	.770	.6	--
30C	7/29/81	80	3.992	23	1.893	32	1.392	<1.0	.026	370	6.064	11	.310	43	.895	<.1	.1
31A	9/21/80	113	5.639	6.1	0.502	24	1.044	1.0	.026	345	5.654	3.0	.085	73	1.520	.1	--
31B	3/26/81	67	3.343	28	2.304	33	1.436	<1.0	.026	340	5.573	13	.367	55	1.145	.4	--
31C	7/29/81	75	3.743	25	2.057	34	1.479	<1.0	.026	350	5.737	6.4	.181	68	1.416	<.1	.1
32A	9/21/80	74	3.693	3.7	0.304	36	1.566	1.0	.026	298	4.884	3.0	.085	34	.708	.1	--
32B	3/26/81	56	2.794	15	1.234	39	1.697	<1.0	.026	275	4.507	14	.395	42	.874	.3	--
32C	7/29/81	57	2.844	16	1.317	43	1.871	<1.0	.026	300	4.917	6.4	.181	45	.937	<.1	.2

Hole Number	Sum Cations meq/l	Sum Anions meq/l	Balance	SAR	TDS mg/l	Specific Conductance mhos/cm
30A	6.733	6.667	-.005	.43	384	695
30B	6.820	6.794	+.0019	.70	365	535
30C	7.270	7.277	+.0005	.83	380	585
31A	7.259	7.210	-.003	.60	430	707
31B	7.108	7.084	+.0017	.85	405	535
31C	7.333	7.305	-.0019	.87	380	565
32A	5.678	5.589	-.008	1.10	312	627
32B	5.751	5.777	-.0022	1.20	330	470
32C	6.034	6.057	+.0019	1.30	320	470

Abbreviations Explanation

mg/l = milligrams per liter
meq/l = milliequivilents per liter
SAR = sodium adsorption ratio
Balance = $\frac{\text{Sum cations - sun anions}}{\text{Sum cations + sum anions}}$
TDS = Total dissolved solids



SPRING NUMBER	SAMPLE DATE	DISSOLVED SOLIDS mg/l
30A	9/21/80	384
30B	3/26/81	365
30C	7/29/81	380
31A	9/21/80	430
31B	3/26/81	405
31C	7/29/81	380
32A	9/21/80	312
32B	3/26/81	330
32C	7/29/81	320

Figure 4-34. Piper Diagram of Chemical Analysis of 3 Springs on NOSR 1. Each Spring was Sampled Several Times to Document Seasonal Variations of Water Quality

The low dissolved solids concentrations and chemical type of all analyses indicates that the springs have moved predominantly through water bearing Zone 1 and possibly Zone 2. The fact that no strong chemical changes are noted over the tract indicates relatively short residence times with little opportunity to undergo the chemical reactions described for the four water bearing zones. The Stiff patterns of the 1981 sample analyses shown on Figure 4-35 also indicate the consistent spring-water quality. Most of the dissolved solids are probably derived from weathered marl-stones, carbonate cemented siltstones, and soil materials rich in caliche-type soil crusts and sodium-calcium carbonate efflorescent minerals often noted in the soils on NOSR 1. Again, the high concentration of carbonate species helps explain the travertine-like deposits often found near springs on NOSR, especially along the East Fork of Parachute Creek. The consistency in chemical analyses agrees with the spring reconnaissance specific conductance data described in Section 4.3.2.4.2, and which shows no distinctive pattern over NOSR 1.

4.3.3 Evapotranspiration

In 1974, Ivan F. Wymore published a report which provides water balance estimates by elevation zones and vegetation types for the Piceance and Yellow Creek watersheds. In his study, Wymore used a modification of the Jensen-Haise method of estimating evapotranspiration. For a detailed discussion of his modification of the Jensen-Haise method, the reader is referred to the original report. For this study, evapotranspiration on NOSR 1 is estimated using the E_t values calculated by Wymore for the different elevation zones and vegetation types in the upper Piceance Creek watershed, and adjusting these values for the elevation and vegetation distribution on NOSR 1.

4.3.3.1 Estimated Evapotranspiration from the NOSR 1 Hydrologic System

NOSR 1, located adjacent to and south of the upper Piceance Creek watershed, ranges in elevation from approximately 9200 feet near the southeastern margin of the Roan Plateau to less than 6600 feet at the western boundary in East Fork Parachute Creek Canyon. However, only the limited area in East Fork Parachute Creek Canyon is below 7500 feet. Table 4-31 summarizes the elevation zone distribution on the NOSR 1 watershed.

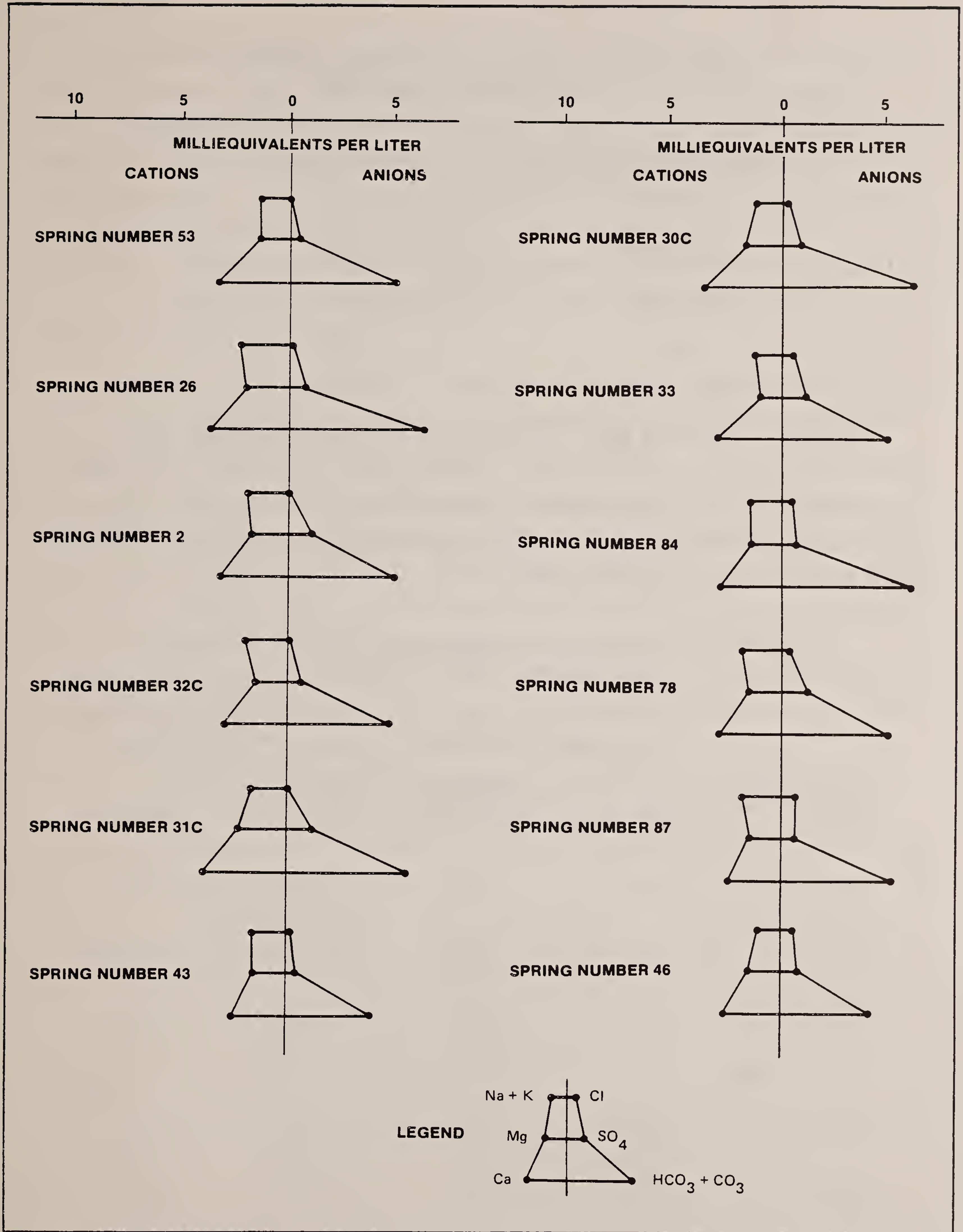


Figure 4-35. Stiff Patterns for Chemical Analyses of July 1981 Spring Samples

Table 4-31. Summary of Elevation Zone Areas on the NOSR 1 Watershed

Elevation Zone (Feet)	Area (Acres)
<7000	106
7000-8000	1,398
8000-9000	26,036
>9000	2,200
TOTAL	29,740

Vegetation types on NOSR 1 are for the most part identical to the vegetation types found in the upper Piceance Creek watershed, and include mixed mountain shrub, coniferous and aspen forest, and rockland. Table 4-32 summarizes the estimated area on NOSR 1 occupied by the different vegetation types at different elevation zones.

Table 4-32. Estimated Distribution of Vegetation Types by Elevation Zone on NOSR 1

	Estimated Distribution By Elevation Zone (Acres)			
Vegetation Type	<7,000 Ft.	7,000 to 8,000 Ft.	8,000 to 9,000 Ft.	>9,000 Ft.
Sagebrush	--	301	8,655	774
Mixed Mtn. Shrub	106	291	6,869	371
Coniferous Forest	--	326	1,552	102
Aspen Forest	--	96	6,870	787
Rockland & Misc.	--	384	2,090	166
TOTAL	106	1398	26,036	2,200

To estimate evapotranspiration on NOSR 1, the E_t values for vegetation type by elevation were taken from Wymore's summary table of estimated evapotranspiration in the upper Piceance Creek watershed. This table summarized the E_t values by elevation zone for all slopes and aspects in this study area. It is recognized that the slope and aspect distribution on NOSR 1 is different than that found in the upper Piceance Creek watershed. However, on average, these differences should not be large. Table 4-33 summarizes the estimated evapotranspiration on the NOSR 1 watershed by elevation zone.

As shown in Table 4-33, the estimated evapotranspiration on NOSR 1 is approximately 19.0 inches. Table 4-34 compares this estimated evapotranspiration and discharge for Water Years 1979 and 1980.

Precipitation, which is the single source of inflow into the NOSR 1 hydrologic system, is estimated in this table from gage records and adjusted snow-pack water-content measurements (Table 4-7). The other two parameters, surface water discharge and evapotranspiration, taken together are an approximation of the total outflow from the NOSR 1 hydrologic system. Comparing the estimated annual values of these parameters shows an agreement of total inflow to total outflow within 10 percent.

Table 4-34. Comparison of NOSR 1 Estimated Total Annual Precipitation to Estimated Total Annual Discharge and Estimated Total Annual Evapotranspiration

Water Year	Estimated Total Annual Precipitation (Inches)	Estimated Total Annual Discharge (Area-Inches)	Estimated Total Annual Evapotranspiration (Inches)
1979	24.4	7.4	19.0
1980	25.2	7.0	19.0

Table 4-33. Estimated Evapotranspiration on NOSR 1

ELEVATION ZONE	VEGETATION TYPE	ACRES ON NOSR 1	ESTIMATED EVAPOTRANSPIRATION NOV-MAR	APR-OCT	TOTAL
<7,000	Mountain Shrub	106	2.50	12.89	15.39
	TOTAL	106	2.50	12.89	15.39
7,000 to 8,000	Sagebrush	301	2.80	14.80	17.60
	Mountain Shrub	291	3.40	14.70	18.10
	Coniferous Forest	326	4.17	14.07	18.24
	Aspen Forest	96	2.79	15.51	18.30
	Rockland & Misc.	384	2.68	13.50	16.18
	TOTAL	1,398	2.61*	14.16*	16.77*
8,000 to 9,000	Sagebrush	8,655	2.41	15.68	18.09
	Mountain Shrub	6,869	3.13	16.95	20.08
	Coniferous Forest	1,552	4.04	15.98	20.02
	Aspen Forest	6,870	2.23	17.18	19.41
	Rockland & Misc.	2,090	3.64	15.44	19.08
	TOTAL	26,036	2.71*	16.25*	18.96*
>9,000	Sagebrush	774	2.61	16.87	19.48
	Mountain Shrub	371	3.13	18.40	21.53
	Coniferous Forest	102	4.04	17.50	21.54
	Aspen Forest	787	3.10	18.66	21.76
	Rockland & Misc.	166	4.70	17.44	22.14
	TOTAL	2,200	3.09*	17.84*	20.93*
NOSR 1 TOTAL		29,740	2.73*	16.26*	18.99*

*Weighted Average.

4.4 NOSR 1 WATER BALANCE

On NOSR 1, the elements which define the total annual water balance include precipitation (inflow), surface water discharge (outflow and storage), groundwater (outflow and storage) and evapotranspiration (outflow).

Precipitation, as detailed in Section 4.2.1, is the single source of inflow into the NOSR 1 hydrologic system. Precipitation was estimated by combining precipitation gage records and snow-pack water content measurements. Because of the more limited recorded period of snow measurements and because the records for Water Year 1981 are not yet available, only the estimates for precipitation in Water Years 1979 and 1980 are included in this report.

Surface water discharge, as detailed in Section 4.3.1, is a combination of runoff and baseflow. Baseflow represents discharge from the groundwater system. Since very little groundwater development has taken place on NOSR 1, the groundwater system is essentially in a state of hydrologic equilibrium. This state of equilibrium implies that the rate of discharge from the system (surface water baseflow) is equal to the rate of recharge with no change in storage. Therefore it is possible to estimate recharge by separating baseflow from total runoff by analyzing the surface water discharge records. This has been done for Water Years 1979 and 1980 in Section 4.3.1.4.

Groundwater, as detailed in Section 4.3.2, is in a steady state on NOSR 1. Since there is very little alluvial material in stream valleys on NOSR 1, it can be assumed that baseflow is a fairly accurate measure of groundwater discharge. Also, because the hydrologic system on NOSR 1 is in equilibrium, baseflow should approximate groundwater recharge. The volume of groundwater on NOSR 1 has not been determined. However, the low rate of recharge implies that large scale groundwater development, in excess of 3,000 acre-feet per year, would probably result in mining the groundwater.

Evapotranspiration, as detailed in Section 4.3.3, is the major source of outflow from the NOSR 1 hydrologic system. In addition, this parameter is the hardest to evaluate directly. However, a reliable estimate of evapotranspiration on NOSR 1 can be obtained by subtracting the total annual surface water runoff from total annual precipitation. To summarize, the annual hydrologic water balance on NOSR 1 can be expressed as follows:

Precipitation = Surface Water Runoff (Direct Runoff + Baseflow) + Evapotranspiration

Table 4-35 summarizes the estimated magnitude of all elements of the hydrologic system for NOSR 1 during Water Years 1979 and 1980.

Table 4-35. Estimated NOSR 1 Water Balance for Water Years 1979 and 1980

Water Year	Estimated Total Annual Precipitation (Inches)	Estimated Total Surface Water Runoff (Area-Inches)		Estimated Total Annual Evapotranspiration (Inches)
		Range of Approximate Direct Runoff	Range of Approximate Baseflow (Equals Groundwater Recharge)	
1979	24.4	6.78 - 6.30	0.59 - 1.07	17.03
1980	25.2	6.27 - 6.01	0.69 - 0.95	18.24

Approximately 30 percent of the total annual precipitation leaves the NOSR 1 hydrologic system as direct surface water runoff. Approximately 10 percent of this surface water runoff is baseflow, which approximates recharge to the groundwater system. Evapotranspiration, estimated by calculating the difference between precipitation and surface water runoff, accounts for approximately 70 percent of the outflow from the NOSR 1 hydrologic system. These estimates of evapotranspiration are within 89 to 95 percent of evapotranspiration value estimated for the vegetation distribution on NOSR 1.

4.5 ESTIMATED WATER IN STORAGE ON NOSR 1

To provide an estimate of water in storage on NOSR 1, two basic parameters are required. These include:

- Estimated fracture porosity
- Estimated saturated volume of the waterbearing zones

For NOSR-1 there are no area-specific estimates of fracture porosity. However, existing estimates of fracture porosity in the Parachute Creek Member of the Green River Formation range from 1.6 percent obtained from an analysis of a core sample (Campbell and Olhoeft, 1977), to 2 to 4 percent porosity calculated from storage-coefficient data obtained from aquifer tests in the Piceance Creek Basin (Banks and Franciscotti, 1976; Robson and Saulnier, 1981). For this report, porosities of 1 and 5 percent were chosen to provide a range which encompasses the existing estimates of porosity.

To estimate the saturated volume of each water-bearing zone, the areal extent of each zone is multiplied by the average zone thickness. Estimated water in storage is then arrived at by multiplying the estimated saturated volume by the fracture porosity. The areal extent of Zone 1 is estimated by removing the outcrop area below the top of the Big Three and approximately 4 aquare miles of area in the vicinity of the Roan Cliffs, from the total NOSR 1 watershed area. The average thickness of Zone 1 on NOSR 1 is about 170 feet. Estimated water in storage in Zone 1 ranges from about 40,000 to 205,000 acre-feet.

The areal extent of Zone 2 is estimated by removing the outcrop area below the top of the Mahogony marker and approximately 4 aquare miles of area in the vicinity of the Roan Cliffs, from the total NOSR 1 watershed area. The average thickness of Zone 2 on NOSR 1 is 20 feet. Estimated water in storage in Zone 2 ranges from 5,000 to 27,000 acre-feet.

The areal extent of Zones 3 and 4 are estimated by removing approximately 4 square miles of area in the vicinity of the Roan Cliffs from the total NOSR 1 watershed area. The average thickness of Zones 3 and 4 are 70 feet and 170 feet, respectively. For Zone 3, the estimated water in storage ranges from about 20,000 to 95,000 acre-feet. For Zone 4, the estimated water in storage ranges from approximately 46,000 to 230,000 acre-feet. Approximate total water in storage in all four zones on NOSR 1 ranges from 110,000 to 560,000 acre-feet.

5. SUMMARY OF FINDINGS

To characterize the hydrologic system on NOSR 1, basic data have been collected on precipitation, surface water, and groundwater. The analyses of these data has provided:

- An estimated water balance for NOSR 1
- Baseline definition of water quality for both surface and groundwater on NOSR 1
- Calculation of aquifer parameters for the four water-bearing zones on NOSR 1
- An estimate of water in storage on NOSR 1

FINDINGS - SURFACE HYDROLOGY

- Precipitation is the only source of inflow into the NOSR 1 hydrologic system. For Water Years 1979 and 1980, total annual precipitation was 24.4 to 25.2 inches, respectively.
- Direct snowmelt runoff, delayed release from storage, and baseflow are the only sources for surface water runoff.
- Only about 1 percent of non-winter precipitation leaves NOSR 1 as surface water runoff. For Water Years 1979 and 1980, less than .1 inch of non-winter precipitation left NOSR 1 as surface water discharge.
- 25 to 30 percent of total annual precipitation leaves NOSR 1 as surface water runoff. In Water Years 1979 and 1980, total surface water runoff was 7.37 and 6.96 area-inches, respectively (18,296 and 17,269 acre-feet).
- Baseflow equals groundwater discharge and accounts for from 8 to 15 percent of total annual surface water runoff. For Water Years 1979 and 1980, estimated baseflow ranged from 0.59 to 1.07 area-inches (1,482 to 2,652 acre-feet).
- 70 to 75 percent of total annual precipitation leaves NOSR 1 as evapotranspiration. For Water Years 1979 and 1980, estimated evapotranspiration ranged from 17.03 to 18.24 inches.
- Overall quality of surface water on NOSR 1 is good, with no exceedence of standards for drinking water or agricultural supplies.

FINDINGS - GROUNDWATER HYDROLOGY

- Calculated transmissivities range from 1.2 to approximately 450 ft^2/day, with most values falling between 2 and 50 ft^2/day.
- Most calculated transmissivities and hydraulic conductivities fall in the permeability range of siltstone.
- Aquifer test responses are typical of fractured media.
- No zone has a uniform response.
- Most drawdown/recovery curves show breaks in slope indicative of negative boundaries.
- Zone 3 tends to have slightly higher transmissivity and hydraulic conductivity values than the other three zones.
- In general, all zones respond to testing as limited aquifers.
- Groundwater types include calcium-bicarbonate, mixed-cation-bicarbonate, and sodium-bicarbonate waters.
- Groundwater quality can be generally characterized as being low in total dissolved solids, having variable water types depending on location, and having generally low concentrations of trace constituents.
- Groundwater recharge is approximated by surface water baseflow, and for Water Years 1979 and 1980 ranged from 0.59 to 1.07 area-inches (1,482 to 2,652 acre-feet).
- Estimated water in storage ranges from 110,000 to 560,000 acre-feet.

6. GLOSSARY

<u>Acre-foot</u>: The quantity of water required to cover one acre to a depth of one foot; equal to 43,560 cubic feet or 325,851 gallons.

<u>Anisotropic</u>: Having physical properties that vary in different directions. In hydrology, permeabilities vary with direction within an aquifer.

<u>Aquifer</u>: (1) A geologic material that will yield water to a well in measurable quantities. (2) An aquifer is a water-saturated geologic unit that will yield water to wells or springs at a sufficient rate so that the wells or springs can serve as practical sources of water supply.

<u>Area-inch</u>: The quantity of runoff from a watershed expressed as inches per unit area; i.e., total annual runoff in acre-feet divided by the area of the watershed in acres, multiplied by 12 inches/foot.

<u>Artesian aquifer</u>: An aquifer overlain by an aquiclude and containing water under artesian conditions.

<u>Artesian water</u>: Ground water under sufficient hydrostatic head to raise the water level above the upper surface of the aquifer.

<u>Aquiclude</u>: A formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring.

<u>Capillarity</u>: The action by which the surface of a liquid, where it is in contact with a solid (as in a capillary tube), is elevated or depressed. Synonym: capillary attraction.

<u>Capillary</u>: A tube of extremely small bore.

<u>Capillary attraction</u>: The apparent attraction or repulsion caused by capillarity.

<u>Cone of depression</u>: A conical depression, on a water table or piezometric surface, produced by pumping.

<u>Confined aquifer</u>: (artesian aquifer) An aquifer in which the water is under greater than atmospheric pressure. The water in a well penetrating a confined aquifer will rise above the top surface of the aquifer, but does not necessarily flow at ground surface.

<u>Cubic feet per second</u>: (cfs or second feet) The discharge of a stream of rectangular cross section, one foot wide and one foot deep, whose velocity is one foot per second; equivalent to 448.8 gallons per minute.

<u>Cubic feet per second-day</u>: (cfs-day) The volume of water represented by a flow of one cubic foot per second for 24 hours. It equals 86,400 cubic feet, or 646,317 gallons.

Depletion: The progressive withdrawal of water from surface- or ground-water reservoirs at a rate greater than the rate of replenishment.

Direct runoff: The water that moves over the land surface directly to streams promptly after rainfall or snowmelt.

Discharge ground water: The process by which water is removed from the zone of saturation; also, the quantity of water removed.

Drainage area: The area drained by a stream above a specific location (for example, a gaging station), measured in a horizontal plane, which is enclosed by a drainage divide.

Effective precipitation (rainfall): (1) That part of the precipitation that produces runoff. (2) A weighted average of current and antecedent precipitation that is "effective" in correlating with runoff. (3) As described by U.S. Bureau of Reclamation (1954, p. 4), that part of the precipitation falling on an irrigated area that is effective in meeting the consumptive use requirements.

Equipotential surface: A surface on which the potential is everywhere constant for the attractive forces concerned.

Evaporation: The process by which water is changed from the liquid or the solid state into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

Evapotranspiration: Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plan transpiration.

Flood plain: A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swifter current. It is called a living flood plain if it is overflowed in times of high water; but is called a fossil flood plain if it is beyond the reach of the highest flood.

Ground water: Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.

Ground-water contributing area: The part of a ground-water reservoir, measured in a horizontal plane, drained by a stream above a specified point. It is bounded by a ground-water divide.

Ground-water reservoir: An aquifer or a group of related aquifers.

Ground-water runoff: That part of the streamflow that consists of water discharge into a stream channel by seepage from the ground-water reservoir; same as baseflow.

Ground-water system: The total dynamic occurrence of ground water from recharge to discharge. The subsurface segment of the hydrologic cycle.

Head: (hydrostatic head) The height of a vertical column of water, the weight of which, in a unit cross section, is equal to the hydrostatic pressure at a point.

Homogeneous: (1) Consisting throughout of identical or closely similar material, which may be a single substance or a mixture, whose proportions and properties do not vary. (2) Of the same kind or nature; consisting of similar parts or of elements of like nature, opposed to heterogeneous.

Hydraulic gradient: Same as pressure gradient. As applied to an aquifer, it is the rate of change of pressure head per unit of distance of flow at a given point and in a given direction.

Hydraulic pressure: Pressure exerted by a fluid against its container.

Hydrogeology: The study of the earth's water in relation to the geology of the earth.

Hydrograph: A graph showing changes in stage, flow, velocity, or other aspects of water with respect to time.

Hydrologic budget: An accounting of the inflow to, outflow from, and storage in a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project.

Hydrologic environment: The size and configuration of ponds and streams, and the extent, boundaries, and water-bearing properties of aquifers.

Hydrology: The science that concerns study of all the waters of the earth.

Impermeable: Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Infiltration: The flow of a fluid into a substance through pores and small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a permeable substance.

Isotropic: Having the same properties in all directions. In hydrology, the term refers to an aquifer in which permeability is the same in all directions.

Joints: Fractures or cracks in rock along which no appreciable movement has occurred.

Laminar flow: That type of flow in which the stream lines or stream surfaces remain distinct from one another (except for molecular mixing) over their entire length.

Nonsteady state: Hydrologic term indicating that the water level in a well being pumped at a fixed rate continuously declines with time.

Part per million: One milligram of solute in 1 kilogram of solution.

Perched ground water: Ground water separated from an underlying body of ground water by unsaturated deposits.

Percolation: Movement under hydrostatic pressure of water through interstices of the rock or soil, except movement through large openings such as caverns.

Permeability, coefficient of: The rate of flow of water in gallons per day, through a cross section of one square foot under a hydraulic gradient of one foot per foot at a temperature of 60°F; also referred to as the field coefficient of permeability when the units are given in terms of the prevailing temperature of the water.

Piezometric surface: The surface to which the water in an artesian aquifer will rise under its full head; the potentiometric surface.

Porosity: The ratio of the aggregate volume of interstices in a rock or deposit to its total volume, expressed as a percentage.

Precipitation: As used in hydrology, precipitation is the discharge of water in liquid or solid state, out of the atmosphere, generally upon the land or water surface. It is the common process by which atmospheric water becomes surface or subsurface water. Precipitation includes rain, snow, hail, and sleet, and is therefore a more general term than rainfall.

Pressure gradient: Same as hydraulic gradient. As applied to an aquifer, it is the rate of change of head per unit of distance of flow at a given point and in a given direction.

Recharge, ground-water: The process by which water is added to the zone of saturation; also the quantity of water added.

Runoff: The water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Soil moisture: Water diffused in the soil or in the upper part of the zone of aeration from which water is discharged by the transpiration of plants or by soil evaporation.

Specific capacity: The rate in gallons per minute of water being withdrawn from a well, divided by the total drawdown of the well. (Example: a well being pumped at 50 gpm with a drawdown of 10 feet has a specific capacity of 50/10 or 5 gallons per minute per foot (gpm/ft).

Specific conductance: The conductance of a cube of a substance one centimeter on a side, measured as reciprocal ohms or mhos. Commonly reported as millionths of mhos or in micromhos, at 25°C.

Specific heat: The ratio of the quantity of heat required to raise the temperature of a body one degree, to that required to raise an equal mass of water one degree.

Specific retention: The ratio of (a) the volume of water retained in a saturated deposit against the pull of gravity to (b) the volume of the deposit.

Specific yield: The ratio of the volume of water drained from a saturated deposit by gravity, to the volume of the deposit.

Steady state: Hydrologic term indicating that the water level in a well being pumped at a fixed rate stabilizes at some time (t) after pumping began, i.e., the water level does not change with time after an initial period.

Storage, coefficient of: The volume of water, expressed as a decimal fraction of a cubic foot, released from storage in a column of the aquifer, having a cross-sectional area of one square foot and a height equal to the full thickness of the aquifer when the head is lowered one foot.

Transitional flow: That type of flow in which the stream lines indicate that the flow regime is changing from laminar to turbulent, or vice versa.

Transmissibility, coefficient of: The rate of flow of water in gallons per day, at the prevailing water temperature, through each vertical strip of aquifer one foot wide, having a height equal to the thickness of the aquifer and under a hydraulic gradient of one foot per foot; also transmissivity.

Transpiration: The quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time; also, the process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere.

Turbulent flow: That type of flow (as in a raging stream) in which the stream lines are thoroughly confused through heterogeneous mixing of flow. The head loss varies approximately with the second power of the velocity.

Unconfined aquifer: (water-table aquifer) The upper limit of the aquifer is defined by the water table. At the water table (the top of the saturated portion of the aquifer), the water in the pore space of the aquifer is at atmospheric pressure.

Underflow: The movement of water in the ground-water reservoir; also, the quantity of water moving in the ground-water reservoir through any vertical plane.

Water table: The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Water-table aquifer: An aquifer containing water under water-table conditions.

Water-table condition: The condition under which water occurs in an aquifer that is not overlain by an aquiclude and that has a water table.

Zone of aeration: The zone above the water table. Water in the zone of aeration does not flow into a well.

Zone of fracture: A zone below the ground surface where the rock has been extensively broken. In hydrology, zones of interconnected fractures may be sources of domestic and stock water.

Zone of saturation: The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Conversion Table for of Hydraulic Conductivity and Transmissivity

Hydraulic Conductivity (K)

Feet per Day (ft/day)	Meters per Day (m/day)	Gallons per Day per Square Foot ($gal/day/ft^2$)
1.0	0.305	7.48
3.28	1.0	24.5
0.134	0.041	1.0

Transmissivity (T)

Square Feet per Day (ft^2/day)	Square meters per day (m^2/day)	Gallons per day per Foot (gal/day/ft)
1.0	0.0929	7.48
10.76	1.0	80.5
0.134	0.0124	1.0

CONVERSION FACTORS

CFS to GPM: Multiply CFS x 448.86
CFS to GPS: Multiply CFS x 7.481
CFS to AF/YR: Multiply CFS x 724.46

CFS - Cubic feet per second
GPM - Gallons per minute
GPS - Gallons per hour
AF/YR - Acre-Feet per year

CFS	GPM	GPS	AF/YR
0.1	45	0.75	72.4
0.2	90	1.5	144
0.3	135	2.2	217
0.4	180	3.0	290
0.5	224	3.7	362
0.6	269	4.5	435
0.7	314	5.2	507
0.8	359	6.0	580
0.9	404	6.7	652
1.0	449	7.5	724
2	898	15	1,449
3	1,347	22	2,173
4	1.795	30	2,898
5	2,244	37	3,622
6	2,693	45	4,347
7	3,142	52	5,071
8	3,591	60	5,796
9	4,040	67	6,520
10	4,489	75	7,244
11	4.937	82	7,969
12	5,386	90	8,694
13	5,835	97	9,418
14	6,284	105	10,142
15	6,733	112	10,867
16	7,182	120	11,591
17	7,630	127	12,316
18	8,079	135	13,040
19	8,528	142	13,765
20	8,977	150	14,489
21	9,426	157	15,214
22	9,875	165	15,938
23	10,324	172	16,663
24	10,773	180	17,387
25	11,222	187	18,112
30	13,466	224	21,734

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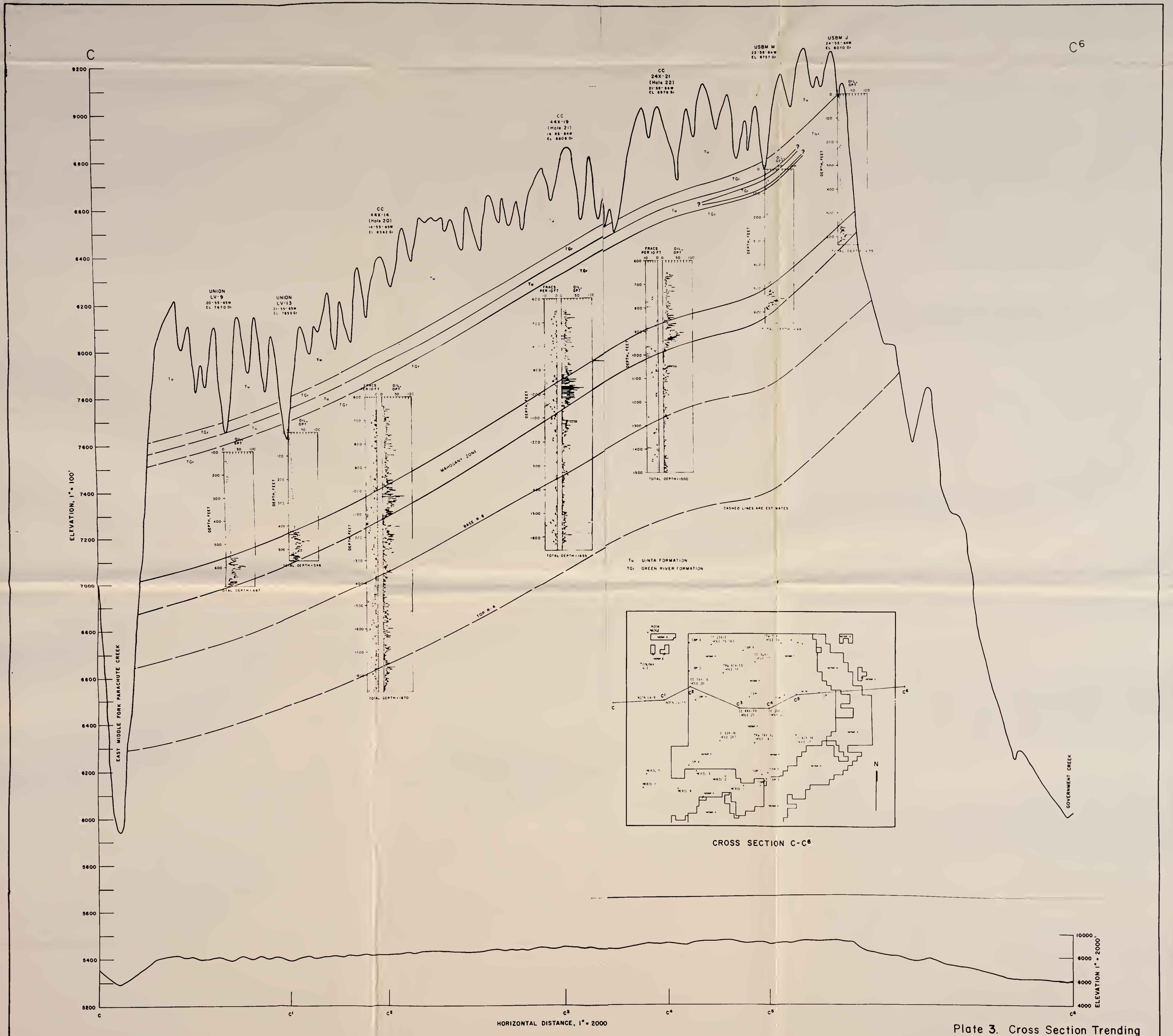

Plate 3. Cross Section Trending East-West Across the Center of NOSRs 1 and 3

Oct, 1980

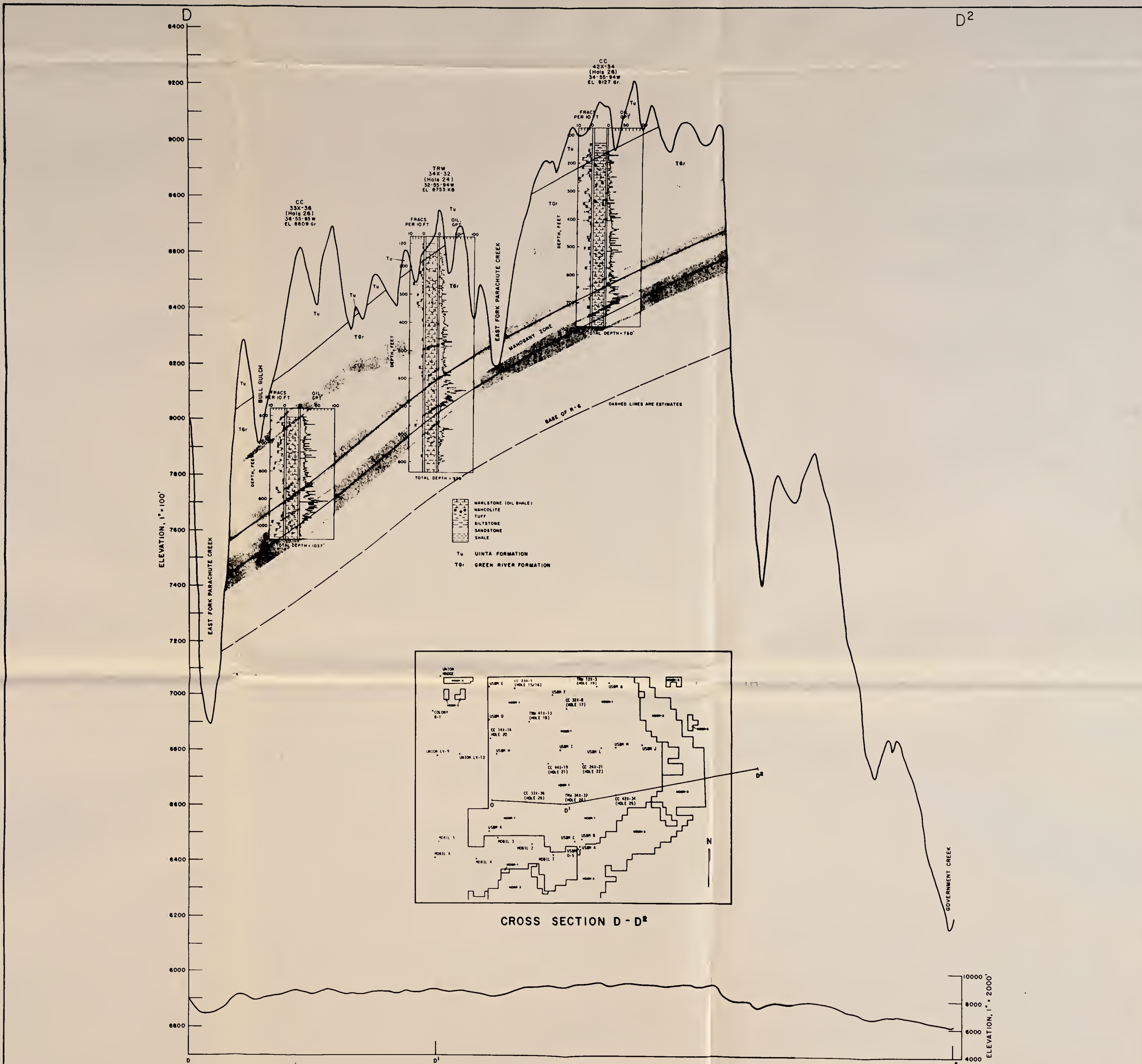

Plate 4. Cross Section Trending East-West Across the Southern Part of NOSRs 1 and 3

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