TECHNICAL REPORT M-77-4

ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

Report 5

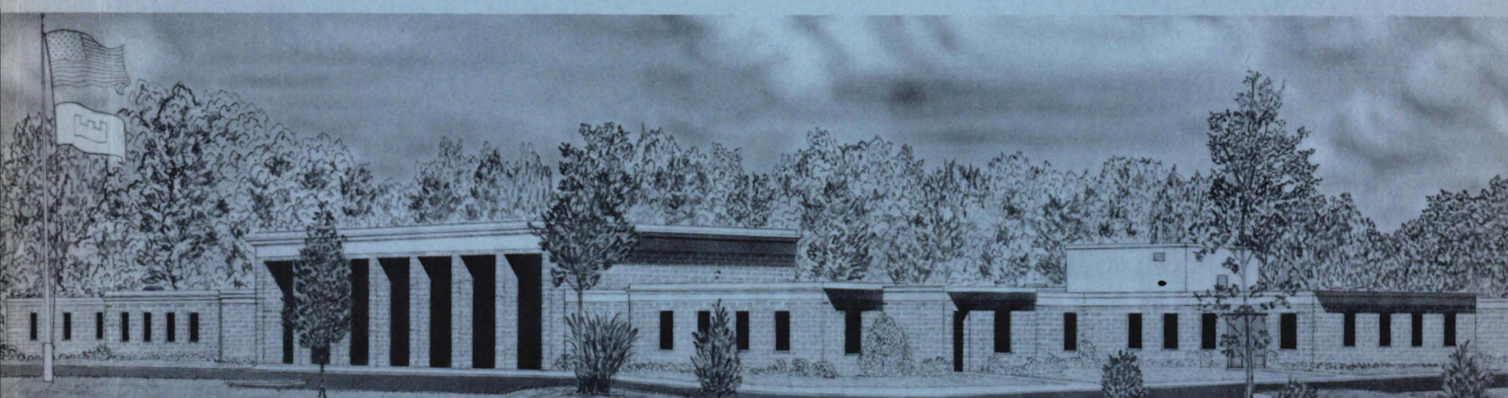
GENERAL GEOLOGY AND SEISMICITY

by

Elba A. Dardeau, Jr., Marcos A. Zappi

Mobility and Environmental Systems Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1977
Report 5 of a Series



Prepared for Directorate of Facilities and Engineering
Fort Carson, Colorado 80913
and
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project 4A162121A896, Task 01, Work Unit 006

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report M-77-4	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES; Report 5, GENERAL GEOLOGY AND SEISMICITY		5. TYPE OF REPORT & PERIOD COVERED Report 5 of a series 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Elba A. Dardeau, Jr. Marcos A. Zappi		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Mobility and Environmental Systems Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 4A162121A896 Task 01, Work Unit 006
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Facilities and Engineering Fort Carson, Colo. 80913 and Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE September 1977 13. NUMBER OF PAGES 57 15. SECURITY CLASS. *(of this report)* Unclassified
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Environmental data
Environmental management
Fort Carson, Colo.
Geology
Military installations
Natural resources
Seismicity

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Environmental protection and enhancement of the natural resources of Army installations has become an integral part of the design, construction, operation, and maintenance activities on those installations. In 1975, the U. S. Army Engineer Waterways Experiment Station began a study to provide environmental baseline descriptions for use in the management of Fort Carson natural resources.

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. ABSTRACT (Continued).

The overall objective of the study was to demonstrate environmental baseline methodologies and to use these methodologies and procedures to collect environmental baseline data that were pertinent to the Fort Carson Long-Range Environmental Program. This report covers the general geology and seismicity of Fort Carson and shows how geologic and seismic parameters relate to engineering and resource management practices on this military installation. It is the fifth of six reports as follows:

Report 1: Development and Use of Wildlife and Wildlife Habitat Data

Report 2: Water-Quality, Meteorologic, and Hydrologic Data Collected with Automated Field Stations

Report 3: Inventory and Assessment of Current Methods for Rangeland Conservation and Restoration

Report 4: Analysis and Assessment of Soil Erosion in Selected Watersheds

Report 5: General Geology and Seismicity

Report 6: Description and Use of a Computer Information System for Environmental Baseline Data

PREFACE

The study reported herein was conducted from 1 August 1975 to 1 March 1977 at the U. S. Army Engineer Waterways Experiment Station (WES) by personnel of the Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL).

The work was authorized by LTC E. R. Hall, Directorate of Facilities and Engineering, Fort Carson, Colorado, and is in support of the Fort Carson Long-Range Environmental Program. The overall Program Managers at Fort Carson were Messrs. D. W. Davis (now retired), Land Management Branch, and M. E. Halla, Environmental Office.

The procedures and methodology used for acquiring on-site environmental baseline data were developed under the Department of the Army Project 4A162121A896, "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management of Military Facilities," Work Unit 006, "Methodology for Characterization of Military Installations Environmental Baselines," sponsored by the Directorate of Military Construction, Office, Chief of Engineers (OCE), U. S. Army. Partial cost of the Fort Carson work that pertained to collecting onsite baseline data was assumed under the auspices of the OCE program mentioned above as research necessary to assess the reliability of the procedures used to support Facility Management Programs.

This report is the fifth of six reports collectively entitled "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural Resources." The individual reports are as follows:

- Report 1. Development and Use of Wildlife and Wildlife Habitat Data
- Report 2. Water Quality, Meteorologic, and Hydrologic Data Collected With Automated Field Stations
- Report 3. Inventory and Assessment of Current Methods for Rangeland Conservation and Restoration
- Report 4. Analysis and Assessment of Soil Erosion in Selected Watersheds
- Report 5. General Geology and Seismicity

Report 6. Description and Use of a Computer Information System for Environmental Baseline Data

The study was conducted under the direct supervision of Messrs. H. W. West, Project Engineer, Environmental Simulation Branch (ESB), and J. K. Stoll, Chief, ESB, and under the general supervision of Messrs. B. O. Benn, Chief, ESD, and W. G. Shockley, Chief, MESL. Messrs. E. A. Dardeau, Jr., ESB, and M. A. Zappi, Environmental Research Branch, ESD, researched and compiled the information on physiography, geologic structure and stratigraphy, groundwater, and seismicity. Mr. C. E. Stevens and Ms. J. I. Schilling, ESB, also contributed significantly to this effort by providing assistance in the preparation of the graphic and illustrative materials. This report was prepared by Messrs. Dardeau and Zappi.

Special acknowledgment is made to Mr. G. R. Scott, U. S. Geological Survey, Denver, Colorado, and to Dr. M. W. Major and Mr. B. W. Presgrave, both of the Department of Geophysics, Colorado School of Mines, Golden, Colorado, for providing assistance and maps from which some of the data presented in this report were abstracted.

Directors of the WES during the study and the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
U. S. Customary to Metric (SI)		
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acres	4046.856	square metres
gallons per minute	0.003785412	cubic metres per minute
parts per million	1.0	milligrams per cubic metre
degrees (angular)	0.01745329	radians
Fahrenheit degrees	0.555	Celsius degrees or Kelvins*
Metric (SI) to U. S. Customary		
metres	3.280839	feet
kilometres	0.6213711	miles (U. S. statute)

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = 0.555(F - 32). To obtain Kelvin (K) readings, use: K = 0.555(F - 32) + 273.15.

ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

GENERAL GEOLOGY AND SEISMICITY

PART I: INTRODUCTION

Background

1. Management of the natural resources of an Army installation is a complex process that involves the reconciliation of two primary objectives. One objective is the need to use the area for the purposes for which it was intended, including weapons firing, vehicle maneuvering, troop bivouacking, and other military activities. If these purposes are to be fulfilled, men and machines must move across or live on the landscape for varying periods of time, thus imposing certain inevitable pressures on that landscape, i.e., plant and animal populations are disturbed, and topographic and hydrologic conditions are altered. The second objective is the desire to maintain the installation's natural resources in as natural a state as possible, or at least in a state aesthetically pleasing and ecologically viable. Many military reservations contain within their boundaries some of the finest wildlife and native conservation areas in their regions. Nevertheless, increased use of some areas and the desire to prevent the mistakes of the past have led to a requirement for far more skillful management practices than have previously been needed.

2. Army Regulation (AR) 200-1 entitled "Environmental Protection and Enhancement," dated 7 December 1973, implements Department of Defense Directive 5100.50 and provides general Department of the Army policy on environmental protection and enhancement of the natural resources of all Army installations in the United States and overseas. The long-term planning and management objectives outlined in this AR require that design, construction, operation, and maintenance activities on an installation must be conducted with minimum environmental impact

on the natural resources of the installation. A Corps of Engineers program entitled "Study of Impact of Environmental Consideration on Military Construction," dated 1 November 1970, emphasized the need for "a system providing necessary technology to support the environmental decision-making processes associated with life-cycle management of Army military facilities."

3. The Environmental Office of the Directorate of Facilities and Engineering (DFAE) is responsible for implementing and managing the Fort Carson Environmental Program.[1] The program consists of air, water, noise, and radiation pollution control; solid waste, toxic, and hazardous materials management; and land management. The Land Management Branch (DFAE) is responsible for the two land management plans: the Land Management Plan for the cantonment area, and the Land Use and Management Plan for downrange training and maneuver areas. The objective of the Land Use and Management Plan is to provide a planning approach for coordinating action to understand and resolve the needs and problems of managers of the natural resources, while outlining procedures for immediate action to maintain and improve those resources. Wildlife management, soil and water conservation, and attention to aesthetic requirements are an integral part of this plan.

4. Physiography, geologic structure and stratigraphy, groundwater, and seismicity are important parameters that must be considered in land management at Fort Carson. It is essential that the significance of each be understood, so that the environmental programs and management plans of the installation will be effective.

5. The regional physiography of the Fort Carson area affects climate, surface hydrology, and sedimentation. Geologic structure and stratigraphy influence soil formation, stability of foundations, and transmissibility of groundwater. The various geologic units can serve as sources of construction and industrial resources or present serious engineering challenges. It is necessary that the resource values and engineering properties of each unit be known. Groundwater sources and presently known and potential water-bearing strata (aquifers) need to be identified and proven because supplies of groundwater at Fort Carson

are inadequate both in terms of quality and quantity. The seismicity of central Colorado must be understood and dealt with when planning new construction or modifying existing structures on Fort Carson.

Purpose and Scope

6. The purpose of the work reported herein was to provide information on those geologic and seismic parameters that relate to and affect the management of the natural resources of Fort Carson. This portion of the program has the following objectives:

- a. Outlining the effect of physiography on climate, surface hydrology, and sedimentation.
- b. Describing geologic structure and stratigraphic units and discussing the engineering importance of these units.
- c. Locating water wells and discussing water-bearing strata (aquifers) in the Fort Carson area.
- d. Correlating seismicity with engineering and resource management problems.

PART II: PHYSIOGRAPHY

7. Fort Carson is located in central Colorado in and adjacent to the Front Range of the Rocky Mountains. It comprises 134,663 acres* in El Paso, Fremont, and Pueblo counties. The physiography of central Colorado influences the climate, determines the surface drainage regimes, and affects sedimentation in the Fort Carson area. Understanding the relationships between physiography and climate, surface hydrology, and sedimentation is essential to the effective management of natural resources.

Regional Physiography[2]

8. The Rocky Mountains extend from Canada to northern New Mexico in a northwest-southeast direction. The easternmost ranges of the Rockies are the Front Ranges. This name is applied to those mountains between the Arkansas River and the Cache la Poudre River near the Wyoming state line. Between Denver and Colorado Springs, the continuity of the Front Range is interrupted by the Platte Canyon through which the South Platte River flows. The section of the Front Range between the South Platte and Arkansas rivers is commonly called the Rampart Range. Pikes Peak (elevation 14,110 ft), just northwest of Fort Carson Reservation, is the highest peak in the Rampart Range. The edge of the foothills of the Rampart Range runs almost north-south through Fort Carson, and it is the boundary between two major physiographic provinces, the Southern Rocky Mountains Province and the Great Plains Province (Figure 1).

9. The major portion of the Fort Carson military reservation lies within the Colorado Piedmont Section of the Great Plains Province. The western portion of the post is in the foothills of the Rampart Range and is, therefore, in the Southern Rocky Mountains Province. The most outstanding physiographic feature of this area is the abrupt wall-like mountain front that forms the boundary between the two provinces.

---

* A table of factors for converting U. S. customary to metric (SI) units and metric (SI) units to U. S. customary units is presented on page 5.

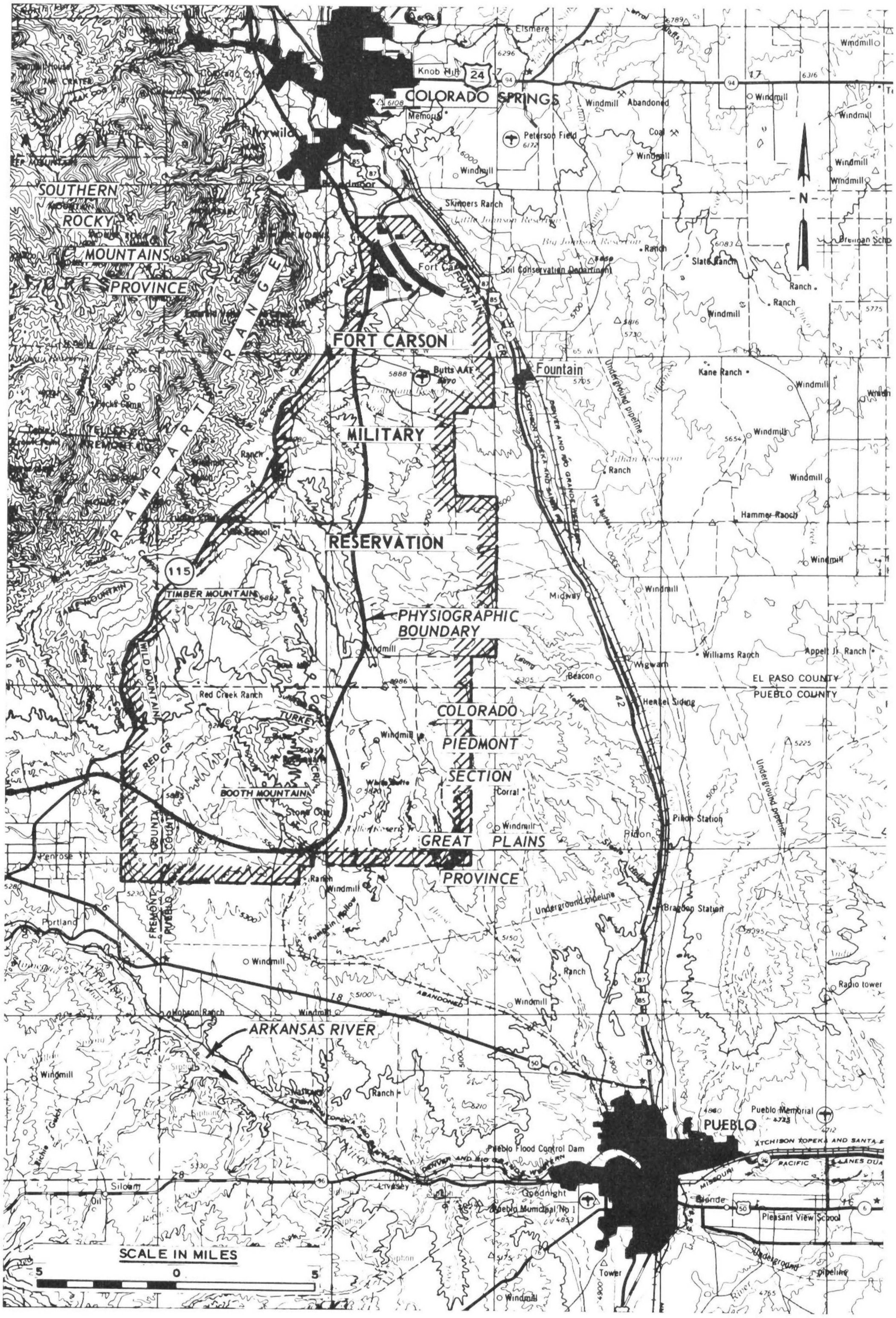


Figure 1. Physiography of the Colorado Springs-Pueblo area of central Colorado (after Fenneman[2])

10. To the west and northwest of Fort Carson, mountains rise sharply to elevations exceeding 9000 ft. Cheyenne Mountain (elevation 9565 ft) is located 5 miles west of the main post area. South of Fort Carson are broad apronlike features that slope to the south and are interrupted by an incised drainage network of intermittent streams and conspicuous hogbacks* of relatively low relief. East of the post are gentle rolling hills and well-defined mesas and terraces. Many water impoundments dot the landscape, especially in the vicinity of the town of Fountain, located 10 miles southeast of the city of Colorado Springs near the eastern boundary of the military reservation.

11. Narrow foothills along the western sector of the reservation are characterized by folded and faulted sedimentary strata, the more resistant beds forming prominent hogbacks (e.g. Wild Mountain). The foothills contain numerous broad, sloping interstream surfaces that stand at various steplike levels above present stream valleys. These surfaces commonly occur as fan-shaped features developed on the eroded surfaces of tilted and truncated strata, mantled by coarse alluvial deposits. Below the interstream surfaces, the streams generally occupy relatively wide and flat valleys. In the eastern portion of the Fort Carson reservation are incised alluvial terraces and pediments** that are mantled by gravel. Extensive alluvial terraces are found along the valleys of Fountain Creek and its main tributaries.

12. Most of the present reservation lies at elevations between 5500 and 6000 ft. Along the western sector, elevations usually exceed 6000 ft. The highest point (6960 ft) is a foothill just northeast of BM 6619 on Colorado State Highway 115. Timber Mountain (elevation 6897 ft), Wild Mountain (elevation 6695 ft), and Booth Mountain (elevation 6454 ft) attain the next highest elevations on the reservation. Local relief† varies from about 900 ft (vicinity of Timber Mountain to

* "A name applied in the Rocky Mountain region to a sharp-crested ridge formed by a hard bed of rock that dips rather deeply downward."[3]

** "Gently inclined planate erosion surfaces carved in bedrock and generally veneered with fluvial gravels."[3]

† "Differences in elevation between highest and lowest points in adjacent locations,"[4] (i.e. a mountain and its adjacent valley, a crest of a stream bluff and the thalweg of the stream, etc.).

valley of Turkey Creek) to about 50 ft on the north end of the reservation.

Physiography and Climate[5]

13. Regional trends in temperature and precipitation are markedly influenced by physiography. Each of these parameters is discussed briefly.

Temperature

14. Winter minimums are 20°-30°F in the Southern Rocky Mountains. The Rampart Range locally affects climatic patterns in the Fort Carson area; these mountains depress annual minimum temperatures 10°-15°F lower than nearby plains areas. They affect average minimum temperatures more than they do the absolute minimums. In the Rockies, the length of the frost-free season (80-120 days) is 40 days less than that of adjacent areas of lower elevations. In general, the western sector of Fort Carson has lower average temperatures than does the eastern sector.

Precipitation

15. Visher[5] points out that the mountains affect average precipitation more than they affect extremes in precipitation. Average annual precipitation in the mountains and the plains is 20 in. and less than 15 in., respectively. Normal numbers of "excessive" rains in both the mountains and lowlands during each of the seasons of the year are as follows:

Season	Number of "excessive" rains
Spring	0-1
Summer	0-1
Fall	0-1
Winter	0

Average frequencies of "brief heavy rains" and "prolonged heavy rains" in the mountains and plains are given below.

	Frequency	
Intensity	Mountains	Plains
Brief heavy rains	Very rare to rare	Rare to occasional
Prolonged heavy rains	Very rare	Very rare to rare

Mountains influence the form as well as the quantity of precipitation. In some areas of the Rockies, average precipitation in the form of snowfall is twice that of the plains areas. These mountain areas maintain their snow cover considerably longer than do the lowlands. The first snowfall of the season in the mountains of the Rampart Range is usually in early autumn; snow may continue to fall until the following summer in the higher elevations. Precipitation data on Fort Carson itself are lacking. The only long-term records are for National Weather Service (NWS) stations at nearby towns and airports. The U. S. Army Engineer Waterways Experiment Station (WES) meteorologic field stations have gathered some climatic data,[6] but the length of time that these data have been collected does not permit analysis for predictions of long-term climatic trends.

Physiography, Surface Hydrology, and Sedimentation

16. The Arkansas, Red, White, and Missouri rivers and their tributaries form the western subbasins of the Mississippi River Basin. Collectively, these streams transport considerable amounts of sediment as they originate in the Rockies and flow across the Great Plains to the Mississippi River. The western subbasins are the greatest sources of sediment in the Mississippi River Basin.[7] There is a wide, gently sloping mass of unconsolidated material overlying the bedrock, which is subject to wind and water erosion. Tributaries to the Arkansas, Red, White, and Missouri rivers are not only incised but are also braided because their sediment loads are high in relation to their discharges. Although precipitation in the watersheds of these rivers is minimal (usually 20-25 in. annually) and varies from year to year, the greatest part reaches the ground in the form of rainfall during the spring and summer months; thus, sediment loads are generally greater during this period than during other periods of the year.

17. Fort Carson is in the drainage basin of the Arkansas River. Principal streams that drain this military reservation are Fountain Creek, Turkey Creek, and Red Creek. These and other streams originate in the mountains to the west and flow through or around Fort Carson,

eventually reaching the Arkansas River. With the exception of Fountain Creek, all of the streams draining Fort Carson are intermittent. On several days during the driest summers, no flows could be measured in Fountain Creek. Man-made impoundments affect flows in Turkey Creek and other intermittent streams. Although these impoundments were designed originally to collect water for livestock, they are now used for various purposes, including erosion control, wildlife water supply, fire suppression, and recreation.

18. Physiography affects surface hydrology and sedimentation at Fort Carson by facilitating runoff. Precipitation occurs in scattered sporadic patterns, and average values are often deceiving. A summer shower, for example, can dump more than 1 in. of rain on one portion of the reservation in a matter of a few hours, while the remainder of Fort Carson receives no precipitation. The rapid rate of rainfall permits only a small portion of the water to be (a) intercepted by vegetation, (b) stored in surface depressions, (c) infiltrated into the ground as soil moisture (both capillary and hydroscopic water), (d) percolated downward through the soil as aquifer recharge, or (e) infiltrated into the ground and to flow laterally through the surface soil to a stream channel as interflow. The majority of the water travels as overland flow (surface runoff) to the nearest stream channel. The proximity of the Rampart Range and the steep slopes on the reservation cause the runoff to be rapid and erosion to be severe. The reach of Fountain Creek from the Colorado Springs gage (0.5 mile east of U. S. Highway 24 Bridge) to the Security gage (approximately 12 miles downstream from the Colorado Springs gage) has a gradient of more than 30 ft/mile.[8] Some of the intermittent streams draining Fort Carson (e.g. Little Fountain Creek and Turkey Creek) have gradients in excess of 100 ft/mile. Discharge and sedimentation data on Fort Carson streams are nonexistent. Discharge data are available only for U. S. Geological Survey (USGS) stations on Fountain Creek, Arkansas River, and minor off-post watercourses.[8] Sediment samples are collected periodically at only a few USGS Arkansas River stations.[7,8] The dearth of these data makes engineering and resource management at Fort Carson difficult.

19. It is known (qualitatively at least) that the physiographic setting and the precipitation patterns on the military reservation cause flash flooding and severe erosion. Floodplains of these streams subject to flooding should be avoided as construction sites. Surface erosion can be minimized by protecting and restoring areas damaged by military training. Techniques available for restoring such areas are discussed in Reference 9. Streambank erosion is avoidable to some degree by implementing techniques to protect the banks where this is necessary (e.g. bridgeheads) and by constructing check dams to reduce flows and to intercept sediment. Current (1976) methods available for streambank protection and unit costs are described in Reference 10.

PART III: GEOLOGIC STRUCTURE AND STRATIGRAPHY

20. As the Rampart Range was forced upward during the Laramide orogeny (late Mesozoic - early Cenozoic eras), the latest episode of Rocky Mountain building, the sedimentary rocks on the flanks were bent, folded, and thrust upward.[11] The results of this activity are numerous north-south- and northwest-southeast-trending faults, anticlines, and synclines. Igneous and metamorphic Precambrian rocks form the core of mountains of the Rampart Range along Colorado State Highway 115 near the western edge of Fort Carson.[12-16] The igneous units vary lithologically and mineralogically and include lamprophyre, monzonite porphyry, and a number of phaneritic units, such as granite, quartz monzonite, granodiorite, and quartz diorite. A biotite gneiss is the only metamorphic unit in the Precambrian sequence. The surface (i.e. outcropping) geologic units on the military reservation include only sedimentary strata deposited during the Cenozoic, Mesozoic, and Paleozoic eras; no igneous or metamorphic units outcrop on Fort Carson. The main structural features of Fort Carson and the outcropping geologic units are discussed below.

Structure

21. Clark and Stearn[11] describe the formation of the present-day Colorado Rockies.

> The structure of the Colorado Rockies was governed by the late Paleozoic Colorado mountains which, through early Mesozoic time, were progressively buried beneath their own debris. These ancient mountains were resurrected in late Cretaceous and early Cenozoic time, when this part of the geosyncline felt the pinch of the Laramide compression, and were raised to heights of more than 14,000 ft to form the highest peaks in the Rocky Mountains.

They further state that the Laramide orogeny was characterized by a series of pulses. Evidence for these orogenic pulses is shown in the character of the sedimentary strata. Sediments derived from early pulses were folded by later movements. Unconformities formed during one pulse were folded or faulted by later orogenic activity. Many early Laramide faults were later folded or intersected by newer faults.

22. Along the boundary of the Great Plains and Southern Rocky Mountains physiographic provinces, the structural displacement exceeds 20,000 ft. This has been accomplished by "reverse faulting in the Precambrian basement rocks and faulting and monoclinal folding in the sedimentary veneer."[17] Grose[17] points out that the majority of the relief occurs within a 2-mile-wide zone along the mountain front. In the Great Plains area, east of Colorado Springs, the Pierre Shale (Upper Cretaceous) and younger beds dip uniformly to the northeast at slopes of 1 to 5 deg.

23. At Fort Carson the evidence of the Laramide orogeny can be seen in the many anticlines, synclines, and faults. The main structural features are shown in Figure 2. Not all of these features have been named, but the names of the major trends are shown. These include Beaver Anticline, Wild Horse Anticline, Red Creek Anticline, and County Line Syncline. Hogbacks that are the remnants of these folded rocks are visible in a number of areas on Fort Carson.

24. Geologic structural features are important in land and resource management at Fort Carson. Three of the most important problem areas are as follows:

- a. Possible seismic activity. The faults indicate a history (even though geologically ancient) of seismic activity. Where such massive movement has already taken place, the possibility of seismic disturbances resulting from additional movement should not be discounted. Information relevant to seismicity at Fort Carson is presented in Part V.

- b. Groundwater investigations. Folds (i.e. anticlines and synclines) and faults warp and displace the geologic strata and alter their local and regional dip. This makes groundwater investigations at Fort Carson (discussed in Part IV) difficult; without a working knowledge of the geologic structure, successful completion of water wells and stratigraphic correlation of adjacent wells and boreholes are often impossible.

- c. Landslides. Landslide areas severely limit construction on Fort Carson. Some areas are subject to further sliding, and other slopes that have not yet failed may become unstable under adverse conditions (e.g. rapid changes in soil moisture content). All landslide areas warrant detailed site investigation before they are disturbed by excavation or construction activity. The location of the Landslide Deposits of the Quaternary are mapped as Qls on Figure 2 and are discussed in paragraph 28.

Stratigraphy

25. Various sedimentary units deposited during the Cenozoic, Mesozoic, and Paleozoic eras outcrop on Fort Carson. Figure 2 illustrates the areal distribution and time-stratigraphic correlation of these strata. Figure 3 shows two generalized geologic cross sections in the Fort Carson area.[18] Cross section A-A' is located north of the reservation and runs east-west through Colorado Springs, and cross section B-B' runs through Pueblo in a southeasterly direction. Rocks deposited during the Cenozoic era are entirely within the Quaternary system. Mesozoic deposits include beds of the Cretaceous and Jurassic systems and one unit that spans the Triassic(?)-Permian (i.e. Mesozoic-Paleozoic) boundary. Outcrops of the Paleozoic era are beds of the Permian and Pennsylvanian systems. Beginning with the youngest beds, the formations of each time-stratigraphic series are described, and their engineering properties are discussed. In those instances where the series has not been described, the next higher time-stratigraphic classification, the system, is used. These descriptions have been abstracted from References 12-16.

Holocene Series

26. The Piney Creek Alluvium (mapped as Qp) is the only entirely Holocene unit that outcrops on Fort Carson. This unit is a gray to brown humic-rich, firmly compact clayey silt and sand and contains pebble lenses in the lower part. Thickness of this unit can be as much as 20 ft. It has a medium to low permeability and is easily excavated. In areas where it is rich in humus, this alluvium is compressible; and where humus is lacking, it is usually easily compacted. Foundation stability is fair to poor for heavy structures, and the clayey portions

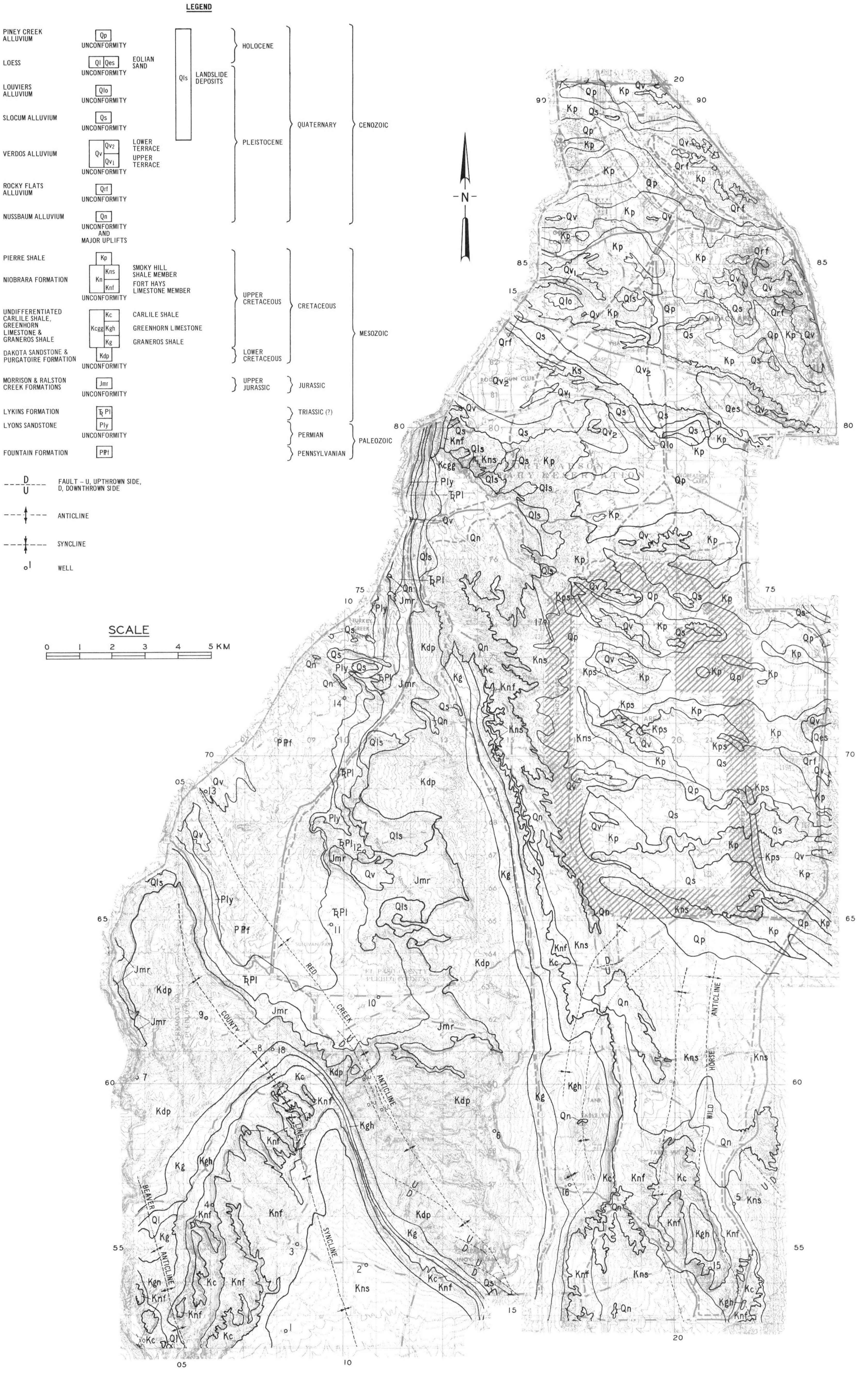
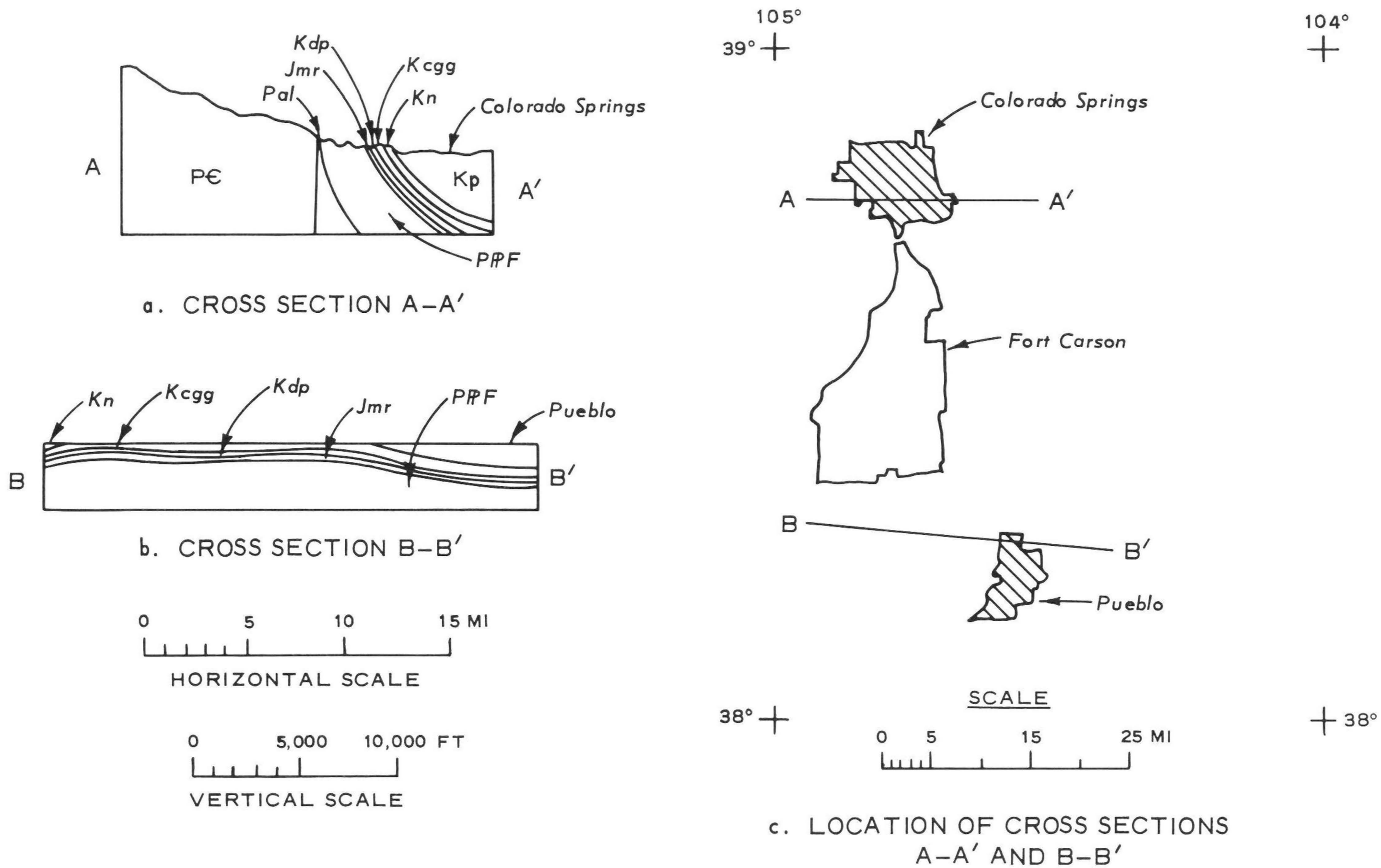


Figure 2. Geologic structure and stratigraphy and water well locations at Fort Carson, Colorado (adapted from Scott[12] and Scott and Wobus[14])



NOTE: P€ = PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS
Pal = PALEOZOIC (PRE–PENNSYLVANIAN) ROCKS

ALL OTHER GEOLOGIC UNIT SYMBOLS ARE THE SAME AS THOSE USED IN FIGURE 2.

Figure 3. Two generalized geologic cross sections in the vicinity of Fort Carson (adapted from Darton[18])

of this unit may have low to medium swelling properties when wetted; therefore, the stability of the foundation is especially poor where this unit is adjacent to arroyos and watercourses. Slope stability is poor to medium, as cut slopes stand vertically along deep arroyos when dry but slump when the base is wetted. Thus, check dams are necessary to prevent erosion. Along the larger streams, this unit is a source of sand and gravel.

Holocene - Pleistocene Series

27. Three units span parts of the Holocene and Pleistocene series at Fort Carson: Landslide Deposits, Loess, and Eolian Sand. Each is discussed briefly.

28. Landslide Deposits. The Landslide Deposits (mapped as Qls) are reddish- to yellowish-brown debris slides and earthflows chiefly on steep slopes along the mountain front, along the edges of pediments, and along the valley of Fountain Creek. All deposits are bouldery and sandy, but clay and silt content varies from abundant where slides involve shaly bedrock to absent where slide material is derived from the Pikes Peak Granite (Precambrian). The upper surface of these deposits is hummocky; the thickness approaches 30 ft. Permeability is low to high depending on clay content. Excavation and compaction are moderately difficult because of steep slopes and boulders. Foundation stability is very poor to good, depending on moisture conditions, slope, and the load imposed; these three factors are also important in determining whether or not further sliding will take place. Earthquake stability is probably very poor for both existing slide areas and potentially unstable areas. Resistance to erosion is good if the surface is covered by boulders and vegetation and fair if the vegetative cover is lacking.

29. Loess. The Loess (mapped as Ql) consists of light-yellowish brown silt and some very fine sand. It has columnar structure and slightly sticky, firm consistency when moist and is hard when dry. A calcareous soil has developed in the upper part. Thickness of this unit may be as much as 10 ft. Permeability of the Loess is low, and excavation and compaction are easy. Walls of trenches may collapse if not

supported by shoring. Foundation stability is generally good as long as the material remains dry.

30. Eolian Sand. This unit (mapped as Qes) is a yellowish-brown, coarse to fine, slightly compact sand; locally in the southernmost outcrops, it also contains some silts and clays. Thickness can be as great as 20 ft. Permeability is medium to high, depending on clay content, and clayey soil in the upper portions can slow the infiltration of water. The Eolian Sand can be compacted, especially if vibratory equipment is used. Walls of trenches can collapse if not supported by shoring. Foundation stability is generally good, but heavy loads may cause settlements, especially if the original consolidation is poor. This unit is readily eroded by wind or water if not covered by vegetation. It is used as a source of commercial sand.

Pleistocene Series

31. The Pleistocene Series has five units outcropping on Fort Carson: Louviers Alluvium, Slocum Alluvium, Verdos Alluvium, Rocky Flats Alluvium, and Nussbaum Alluvium. Each is discussed briefly.

32. Louviers Alluvium. The Louviers Alluvium (mapped as Qlo) is a yellowish-brown gravelly alluvium containing pebbles, cobbles, and boulders. This alluvium, which outcrops along Fountain Creek, is weakly compacted, poorly sorted, and well stratified. It reaches a maximum thickness of 40 ft. Permeability is generally high; however, infiltration may be slow owing to clayey soil in the upper part of the unit. Excavation is generally easy with light equipment, and compaction is moderately easy using vibrator compactors and pneumatic-tired rollers. Foundation stability is generally good, and slope stability is fairly good; however, some shoring may be necessary in trenches. Resistance to erosion is good except in coarse sand facies. This unit is a source of sand and gravel.

33. Slocum Alluvium. This unit (mapped as Qs) is a moderate-reddish-brown, poorly sorted, moderately compacted, stratified gravel containing layers of clay, silt, and sand, and clay balls derived from shaly bedrock. Near the mountains, outcrops of this alluvium contain larger and more abundant boulders than do the eastern outcrops. Stones

are weathered and coated with calcium carbonate, and the upper part of most deposits contains a calcareous soil. Total thickness may be as much as 40 ft. Permeability varies from high in gravel to low in clayey and silty layers. Excavation and compaction are usually easy except in bouldery deposits. The material in vertical cuts generally slumps after a short time to a slope of 25 deg or less. This unit is relatively resistant to erosion and is a source of sand and gravel.

34. Verdos Alluvium. The Verdos Alluvium is locally divided into a lower terrace (mapped as Qv_2) and an upper terrace (mapped as Qv_1); where the two terraces cannot be differentiated, the unit is mapped as Qv. It is a brown, poorly sorted, moderately compacted, stratified gravel containing lenses of sand, silt, and clay. Deposits near the mountains contain the largest stones, and the upper part of most deposits contains a calcareous soil. In some localities, thickness may approach 100 ft. Permeability is high in gravel but generally low in clay and silt lenses. Excavation and compaction are usually easy except in bouldery deposits. Foundation stability is good for small structures, but this material is subject to failure when wetted under heavy loads. In vertical cuts, the Verdos Alluvium generally slumps after a short time to a slope of 25 deg or less. This alluvium resists erosion and is a source of sand and gravel.

35. Rocky Flats Alluvium. This unit (mapped as Qrf) occurs as a reddish-brown pebble, cobble, and boulder gravel in the western part of the area. Some clayey coarse sand is present in the eastern part of the area. The alluvium is poorly sorted, firmly compacted, and stratified. Stones are altered and coated by calcium carbonate, and the upper part of most deposits contains a calcareous soil. Local thicknesses exceed 50 ft. Permeability is moderately high, and excavation and compaction are easy except when large boulders are present. Foundation and slope stability are good. Excavations stand in vertical walls for months but eventually slump to 25-deg slopes. This unit is resistant to erosion and is a source of sand and gravel.

36. Nussbaum Alluvium. The Nussbaum Alluvium (mapped as Qn) is a brownish-gray, poorly sorted, firmly compacted, stratified bouldery

alluvium. On Fort Carson it outcrops in the area south of Little Fountain Creek where the gravelly material is derived from granite, porphyry, and gneiss. Color, grain size, degrees of stratification, compaction, and sorting vary with parent material. Stones are altered by weathering and are coated with calcium carbonate. The upper part of most deposits contains a calcareous soil. Thickness exceeds 80 ft. Excavation and compaction are easy except where there are large boulders. This material dusts badly when used as road metal. Foundation stability is good, and slope stability is fairly good. Vertical cuts stand for a long time and then slump to a slope of 25 deg or less. This unit is relatively resistant to erosion and is used as a source of sand and gravel.

Upper Cretaceous Series

37. There are five Upper Cretaceous units at Fort Carson: Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale. Each is discussed briefly.

38. Pierre Shale. This formation (mapped as Kp) is principally a marine shale containing bentonite beds and well-preserved fossils. The upper part is a clayey shale containing fibrous aragonite and cone-in-cone structure,* underlain by dark-gray shaly sandstone, a clayey shale containing large, irregular gray limestone masses that form the caps for conical mounds called tepee buttes, soft shaly yellowish-brown sandstone, silty noncalcareous shale containing ironstone modules, thin ridge-forming siltstone, and an olive-gray clayey calcareous shale. Thickness ranges from 3150 to 4800 ft. Permeability of this unit is low. Excavation and compaction are easy except for tepee buttes. Foundation stability is poor because much of the shale has a low to very high swelling potential, especially in the bentonite beds. Slope stability is poor, and vertical cuts may collapse; even shale in slopes no steeper than 5 deg may slide if the toe of the slope is removed. Erosion resistance is poor, and check dams are necessary. This formation is a source of clay for brick or tile production and of bloated clay for

---

* "A concretionary structure... characterized by the development of a succession of cones, one within another."[3]

the manufacture of lightweight aggregate.

39. Niobrara Formation. The Niobrara Formation consists of the Smoky Hill Shale Member (mapped as Kns) and the Fort Hays Limestone Member (mapped as Knf). In some portions of Fort Carson, these two members are not differentiated (mapped as Kn). Each member is described and its engineering properties are given in the following subparagraphs:

a. Smoky Hill Shale Member. This is a yellowish-brown, soft, thin-bedded calcareous shale and interbedded thinly layered limestone. Thickness is probably more than 530 ft. Permeability is low. Excavation is fairly easy in the shale but moderately difficult in the chalk and limestone beds. A small backhoe can excavate only with great difficulty in the lower limestone to a depth of 10 ft; the shale and limestone unit requires more powerful equipment. Compaction is very easy except where large blocks of rock are present. Foundation stability is fairly good; however, the shale contains some swelling clay and bentonite beds. Slope stability is good, but erosion resistance is moderately poor, and check dams are probably needed. This member is a potential source of cement rock and smelter limestone.

b. Fort Hays Limestone Member. This member consists of gray, hard limestone beds, 1-26 in. thick, separated by thin shale partings. Total thickness is about 30-40 ft. Permeability is poor, and excavation and compaction are difficult. Foundation stability is excellent. Slope stability is also excellent except on an undercut dip slope. Erosion resistance is good. This member is a source of cement rock and smelter limestone.

40. Carlile Shale, Greenhorn Limestone, and Graneros Shale (undifferentiated). In the northwest portion of Fort Carson adjacent to the foothills, these three Upper Cretaceous Series formations occur as relatively small outcrops and are not differentiated; they are mapped as Kcgg. On the southern portion of the reservation, they are differentiated at the formation level. Descriptions and engineering properties of the three formations are given in paragraphs 41-43.

41. Carlile Shale. The Carlile Shale (mapped as Kc) consists of four members: (a) Juana Lopez Member, a grayish-brown hard calcarenite;* (b) Codell Sandstone Member, a yellowish-gray massive to thin-bedded

---

* A sandy limestone composed of shell fragments.[14]

sandstone; (c) Blue Hill Shale Member, a dark-gray noncalcareous shale containing large septarian* concretions; and (d) Fairport Chalky Shale Member, a yellowish-gray soft calcareous shale. Thickness of the Carlile is about 150 ft. Permeability is low except in the Codell. Excavation and compaction are difficult in the Juana Lopez and Codell but moderately easy in the other two members. The Juana Lopez and Codell have excellent foundation stability, whereas the shale members have fair to poor stability and have some swelling properties because of bentonite beds. Only the Juana Lopez and Codell stand in vertical cuts and resist erosion; the other members are stable on slopes of 5 to 10 deg and erode readily.

42. Greenhorn Limestone. This formation (mapped as Kgh) has three members: (a) Bridge Creek Limestone Member, consisting of interbedded gray dense limestone and gray hard calcareous shale layers; (b) Hartland Shale Member, consisting of a gray shaly calcarenite; and (c) Lincoln Limestone Member, consisting of grayish-brown thin beds of hard calcarenite and shaly calcarenite containing marker** bentonite at the base. Thickness of the Greenhorn is approximately 75 ft, and permeability of the formation is low. Excavation and compaction are difficult in the Bridge Creek and moderately easy in the other two members. Foundation stability is excellent for the Bridge Creek and fair to poor for the other two members, which also have swelling properties. The Bridge Creek stands well in vertical cuts and resists erosion; the shale members are stable only in slopes of 5 to 10 deg or less and erode readily.

43. Graneros Shale. The Graneros Shale (mapped as Kg) is a dark-gray, hard calcareous shale. It is approximately 75 ft thick and has low permeability. Excavation and compaction are moderately easy. Foundation stability is fair to poor, and the formation has some swelling properties due to the presence of bentonite beds. It is stable only in

---

* A structure consisting of an irregular polygonal system of internal cracks that are usually filled with calcite or other minerals.[3]

** A stratigraphic bed generally selected for lithologic characteristics and used for geologic correlation in field (or subsurface) mapping.[3]

slopes of 5 to 10 deg or less and erodes readily.

Lower Cretaceous Series

44. The Dakota Sandstone and the Purgatoire Formation (undifferentiated and mapped as Kdp) is the only Lower Cretaceous Series unit represented at Fort Carson. The Dakota Sandstone, which conformably overlies the Purgatoire Formation, is a yellowish-brown, fine-grained crossbedded sandstone containing some shale (Dry Creek Canyon Member). Thickness of the Dakota is about 160 ft in the middle part. The Purgatoire Formation consists of two members: (a) Glencairn Shale Member, which contains shale, clay, and some gypsum; and (b) Lytle Sandstone Member, which contains fine- to coarse-grained pebbly beds. Thickness of the Purgatoire ranges from 160 to 200 ft. This undifferentiated unit has medium permeability. Excavation is difficult, and blasting may be required. Compaction is difficult. Foundation stability is excellent, as is slope stability, but rocks on dip slopes may slide if undercut. Erosion resistance is excellent. The Dakota Sandstone is an excellent aquifer capable of producing groundwater at relatively high sustained yields. The water-bearing properties of this formation are discussed in more detail in Part IV.

Upper Jurassic Series

45. The only unit represented at Fort Carson belonging to the Upper Jurassic Series is the undifferentiated Morrison and Ralston Creek formations (mapped as Jmr). The Morrison Formation consists of a varicolored gray, maroon, and green siltstone and claystone and thin beds of sandstone, limestone, and conglomerate. Thickness of the Morrison is 225 ft. The Ralston is a 20-ft-thick unit consisting of sandstone, siltstone, gypsum, and beds of limestone containing red jasper grains. This undifferentiated unit has low permeability. Excavation is moderately difficult below a 5- to 10-ft-thick weathered zone. It compacts with relative ease. Foundation stability is fair to poor, but slope stability is moderately good. Erosion resistance is only fair, and check structures are probably needed.

Triassic(?)-Permian System

46. The Lykins Formation (mapped as ₧ Pl) spans the

Mesozoic-Paleozoic boundary. It consists of a maroon and green silty shale; a white, maroon, and pink fine-grained sandstone; and limestone and gypsum layers. Thickness of the Lykins is 180 ft. Permeability is low to medium. Excavation and compaction range from difficult to impossible for small power equipment. Foundation stability is good except on the gypsum. Slopes on most beds stand vertically for a long time. This formation is fairly resistant to erosion.

Permian System

47. The Lyons Sandstone (mapped as Ply) is the only outcropping unit that is entirely within the Permian System. It is a red and yellowish-gray, fine-grained sandstone consisting of resistant upper and lower ridge-forming units separated by less resistant sandstone. Formation thickness is 700-800 ft. Excavation and compaction are difficult to impossible for small power equipment. Foundation stability, slope stability, and resistance to erosion are all excellent.

Permian-Pennsylvanian System

48. The oldest unit outcropping on Fort Carson is the Fountain Formation (mapped as PIPf). This consists of a moderate-reddish-brown arkosic conglomerate, a yellowish-gray coarse-grained arkosic sandstone, and thin layers of pale-green and dark-reddish-brown shale. At the base of the formation is the Glen Eyrie Shale Member, which consists of gray sandstone, sandy shale, and black shale about 100 ft thick. Permeability is medium to low. Excavation and compaction are very difficult to impossible for small power equipment. Foundation stability, slope stability, and erosion resistance are excellent.

PART IV: GROUNDWATER

49. Supplies of groundwater at Fort Carson are inadequate both in terms of quality and quantity. Wells at a number of downrange sites provide limited quantities of water for troops, wildlife, and fire-fighting. Table 1 enumerates the present (1977) water wells that are producing at Fort Carson (Figure 2) and gives some pertinent facts about them, including location, probable aquifer, and well depth, if known. The probable aquifer was determined by considering the surface geology (Figure 2), well depth, and surface elevation. The term "probable aquifer" is used, since boring data were available for only three locations (15, 16, and 18), and local structure and stratigraphy can be anomalous at any given well location. Where well depth was not known, no attempt was made to determine the probable aquifer.

50. The cantonment at Fort Carson, which houses an average of 20,000 troops at any given time, obtains its water supply from the city of Colorado Springs, Colorado. Colorado Springs' water supply comes from watersheds in the Pikes Peak region and on the western slopes of the Rockies (i.e. on the western side of the Continental Divide). This water is transported by means of tunnels and pipelines to the city and eventually to Fort Carson.

51. Major potential aquifers in the Fort Carson area are the various Quaternary alluvial deposits and the Dakota Sandstone. A number of other minor strata can possibly yield smaller quantities of highly mineralized water. Each of the major aquifers will be discussed in separate sections, and the minor aquifers will be treated collectively in a single section; in addition, formation descriptions are provided for any aquifer that does not outcrop at Fort Carson (i.e. not presented in Part III).

Alluvial Aquifers

52. The various Quaternary alluvium units in the Fort Carson area consist of deposits of gravels and sands with minor amounts of

cobbles, silts, and clays. These materials are derived largely from the weathered granites, sandstones, limestones, and shales of the mountain and upland areas. The alluvial aquifers fill the deeply cut valleys and yield sparse to abundant supplies of water depending on the degree of saturation. Groundwater yield is directly related to climatic conditions and varies directly with the proximity of perennial watercourses. In 1970, Major et al.[19] reported sustained yields as high as 3150 gpm in the Arkansas River Valley. Jenkins[20] states that irrigation wells in the alluvium of Fountain Creek had yields as great as 1340 gpm in 1964. Tests conducted in the alluvium of Red Creek, an intermittent stream on Fort Carson, showed a probable yield range of 10 to 50 gpm.[21] In addition to Red Creek, other intermittent streams flowing through Fort Carson that are hydrologically connected to the drainage system of the Arkansas River Basin are Turkey Creek, Dry Creek, and Wild Horse Creek. Wells drilled into the alluvium of these minor streams cannot be expected to yield more than 1 gpm on a sustained basis.[22]

53. The most promising area, in terms of its sustained yields, is obviously in the valley of Fountain Creek. The alluvium of Fountain Creek unconformably overlies the Pierre Shale. Figure 4 shows the location of water wells producing (in 1964) from the alluvium of this creek at the northeast corner of Fort Carson in the vicinity of the town of Security, Colorado. Very few of the wells were on Fort Carson itself, since the majority of the floodplain is along the left (or east) bank of Fountain Creek. Fountain Creek has encroached upon the high right banks of the Pierre Shale on Fort Carson. The aquifer in this area consists of an alluvium-filled former channel, known as the Widefield Buried Channel (Figure 4). It is cut into the Pierre Shale and is hydraulically connected with the present-day perennial stream only at the upper and lower ends of the area where the stream crosses the old channel. Figure 5 presents a cross section (C-C') of Fountain Valley with depths to the Pierre Shale; the Fort Carson boundary is the present thalweg of the creek.

54. Jenkins[20] reported that groundwater from wells drilled in the alluvium of Fountain Creek contained averages of 137-ppm calcium

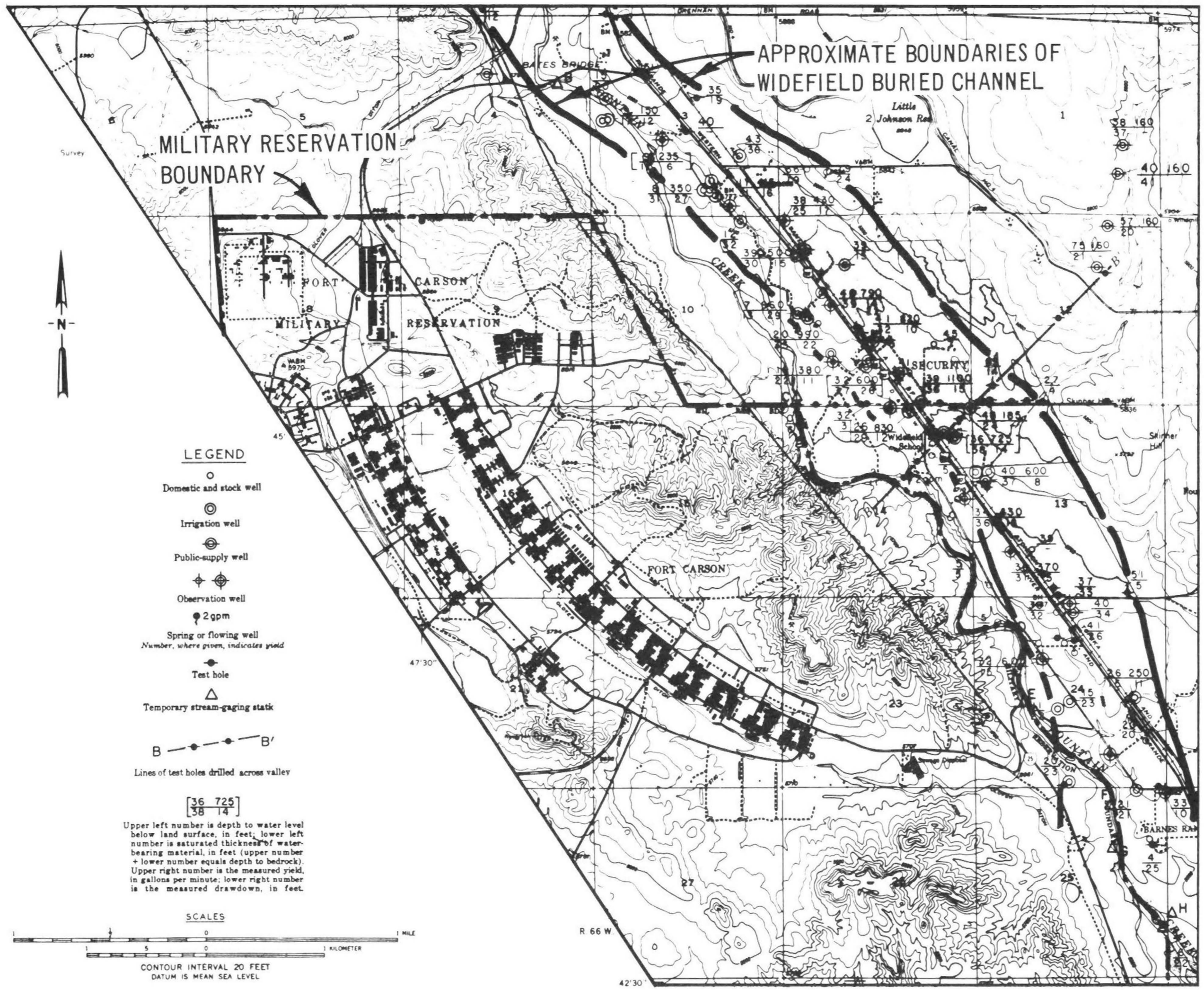


Figure 4. Water well data and locations of temporary stream-gaging stations, Fountain Valley, El Paso County, Colorado, in 1964 (adapted from Jenkins[20])

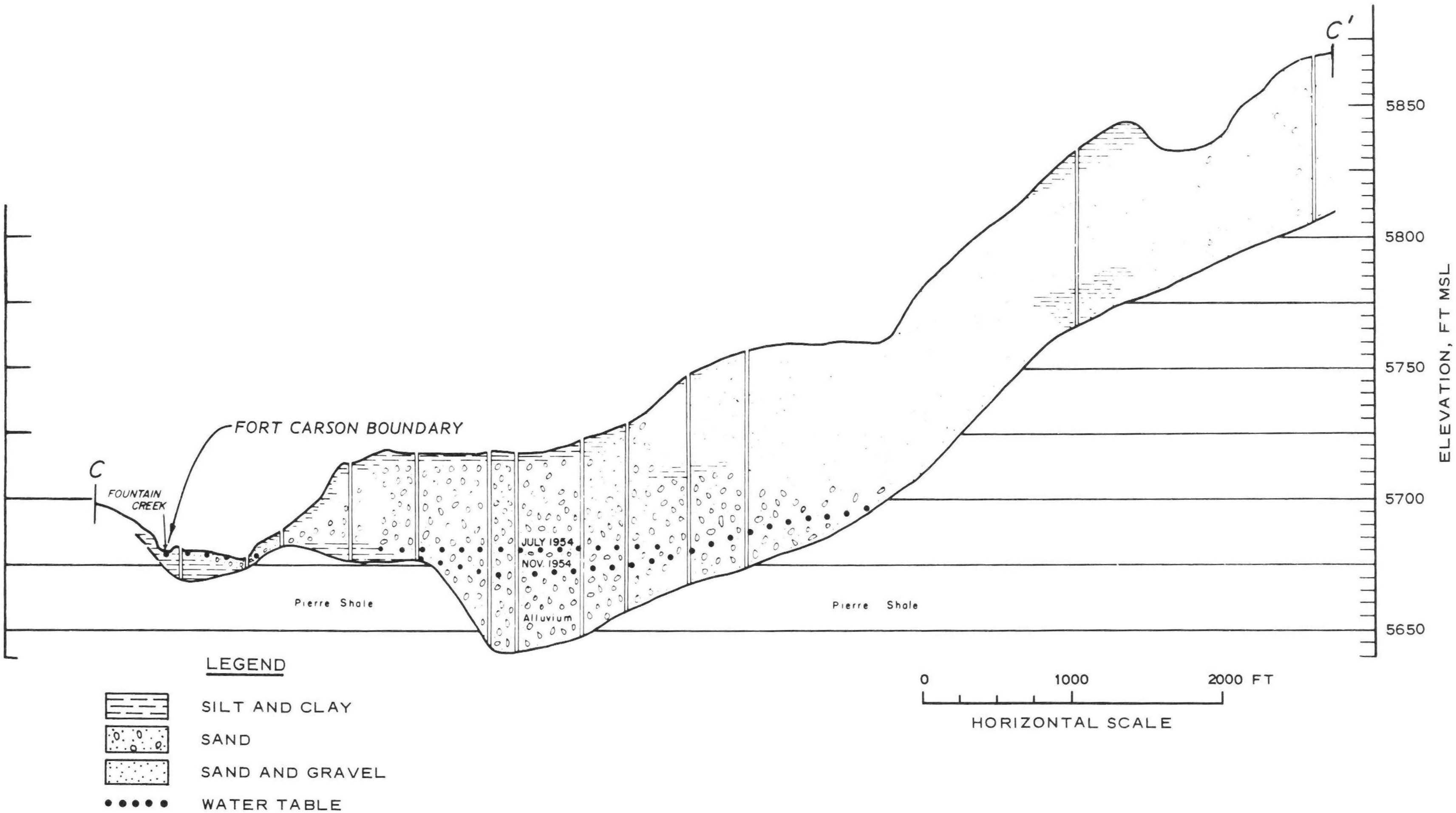


Figure 5. Cross section (C-C') of Fountain Valley, El Paso County, Colorado (adapted from Jenkins[20])

and 25-ppm magnesium with minor amounts of other constituents based on 14 samples. The amount of dissolved solids is used as a measure of total mineralization of water and is a significant criterion for most uses. Analyses from six Fountain Valley wells showed a range of 115 to 1,560 ppm, with the average value being 749 ppm. U. S. Public Health Service (USPHS) Standards[23] indicate that dissolved solids should not exceed 500 ppm, but as much as 1,000 ppm may be acceptable for human consumption. Livestock have been known to survive in water containing as much as 10,000-ppm dissolved solids; however, their well-being may be noticeably affected by water containing more than 3,000 ppm.[20]

Dakota Sandstone Aquifer

55. The Dakota Sandstone is the principal artesian aquifer at Fort Carson. Groundwater is transmitted along open joints and fractures and recharged by percolating surface runoff along the western side of the reservation. In the State of Colorado, wells in the Dakota have yielded from 1 to 250 gpm, with the large range of yield controlled principally by the degree of fracturing in the rock. Figure 6 shows depths to the top of the Dakota Sandstone. Although this map was originally published as part of a 1906 paper,[18] it is still valid. Depths to the Dakota Sandstone in more recent studies (e.g., the wells discussed in References 21 and 24) correspond with those of Figure 6.

56. Table 1 shows three major pump-driven (15, 16, and 18) and three minor wind-driven (7, 8, and 9) water wells at Fort Carson producing from the Dakota Sandstone aquifer. Figure 7 presents the completion data for well 18 at Camp Red Devil. This well has an estimated sustained yield of 150 gpm. Figure 8 summarizes the completion data for wells 16 and 15 in Tank Tables VII and VIII, respectively. The sustained yield of well 16 is 200 gpm and well 15, 30 gpm. No values for sustained yields are available for wells 7-9.

57. Results of water-quality analyses[21,24] for the three major Dakota wells are as follows:

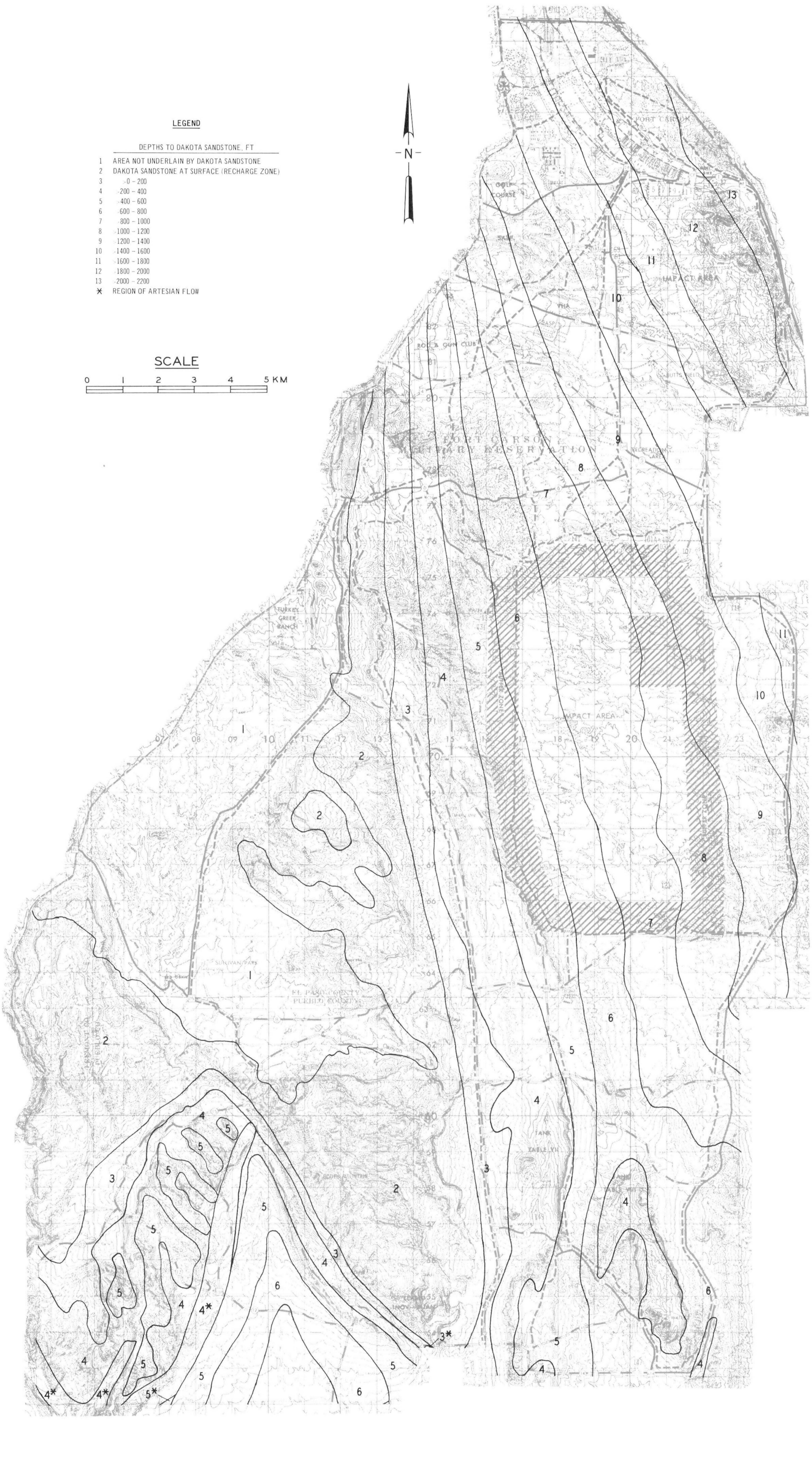
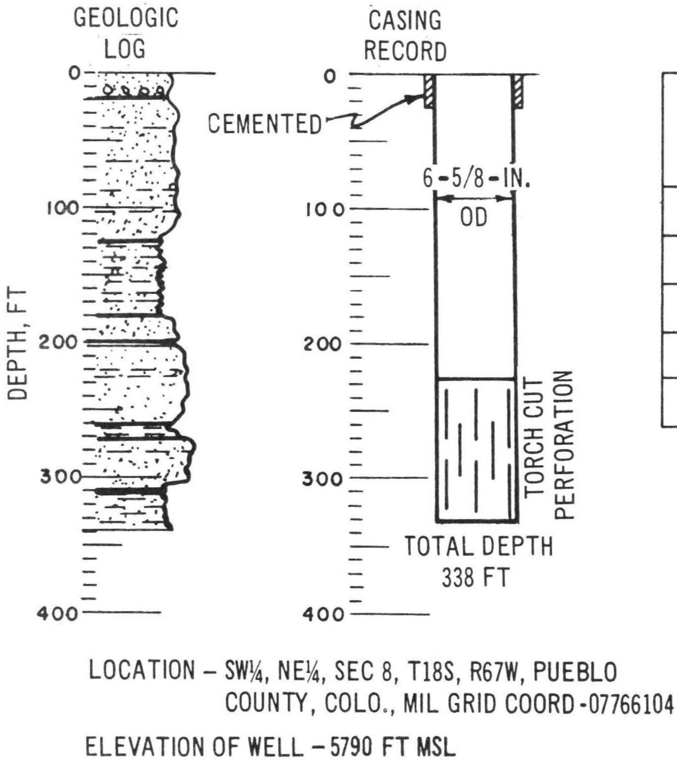


Figure 6. Depths to the top of the Dakota Sandstone, Fort Carson, Colorado (adapted from Darton[18])



PUMPING TEST DATA

DATE	DEPTH SET FT	YIELD GPM	DRAW-DOWN FT	REMARKS
9/29/67	309	230	134	SWL 84 FT
				TEST CONDUCTED FOR 24 HR
				RECOVERY TO SWL 81 FT AFTER 3-1/2 HR
				ESTIMATED SUSTAINED YIELD – 150 GPM
				TYPE OF PUMP – SUBMERSIBLE 30 HP REDA NO. 15 G 180

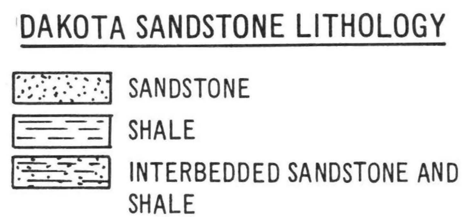
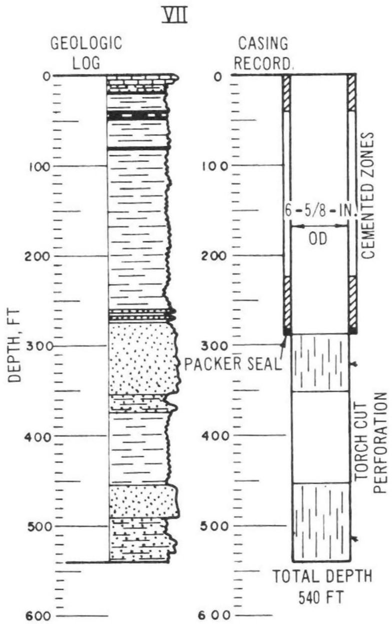


Figure 7. Completion data, well 18, Camp Red Devil, Fort Carson, Colorado (adapted from U. S. Army Engineer District, Omaha, CE[21])



LOCATION – SW¼, SW¼, SEC 20, T18S, R66W, 6PM, MIL GRID COORD-16775683

ELEVATION OF WELL – 5630 FT MSL

TABLE VII

PUMPING TEST DATA

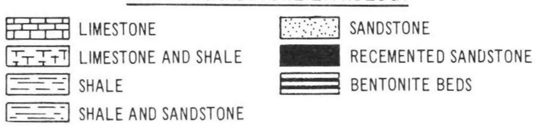
DATE	DEPTH SET FT	YIELD GPM	DRAW-DOWN FT	DURATION OF TEST, HR	REMARKS
1/28/68	365	65	24	1.0	SWL 147 FT (PREPUMPING TEST)
		100	45	1.5	RECOVERED TO 155 FT IN 1/2 HR
		200	138	1.0	ESTIMATED SUSTAINED YIELD – 200 GPM
		150	91	20.5	TYPE OF PUMP – 30 HP ELECTRIC SUBMERSIBLE PUMP

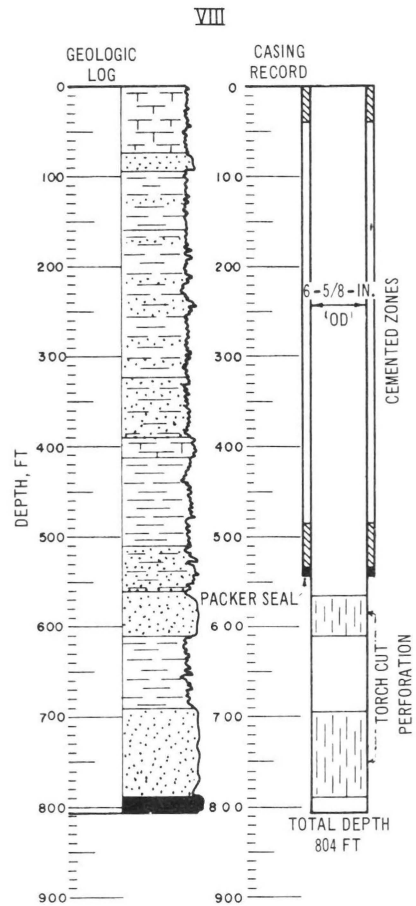
TABLE VIII

PUMPING TEST DATA

DATE	DEPTH SET FT	YIELD GPM	DRAW-DOWN FT	REMARKS
2/6/68	700	30	312	SWL 245 FT (PREPUMPING TEST) TEST CONDUCTED FOR 24 HR
				RECOVERED TO 263 FT IN 65 MIN
				ESTIMATED SUSTAINED YIELD – 30 GPM
				TYPE OF PUMP – 15 HP ELECTRIC SUBMERSIBLE PUMP

DAKOTA SANDSTONE LITHOLOGY





LOCATION – NE¼, SE¼, SEC 33, T18S, R66W, 6PM; MIL GRID COORD-21945438

ELEVATION OF WELL – 5535 FT MSL

Figure 8. Completion data, wells 16 and 15, Tank Tables VII and VIII, respectively, Fort Carson, Colorado (adapted from U. S. Army Engineer District, Omaha, CE[24])

Well No.	Hardness, ppm			ppm	
	$CaCO_3$	Ca	Mg	SO_4	Fe
18	336.0	290.7	45.3	275.0	0.2
16	362.0	307.8	54.2	120.0	0.15
15	260.0	205.2	54.8	104.0	1.0

These tests showed that all three wells produced water acceptable for human consumption. As noted, the sulfate content and hardness in well 18 were slightly higher than that recommended by the USPHS, but the continued use of the well could possibly reduce the amount of sulfate coming from the formation. These analyses showed high hardnesses on wells 16 and 15 and a high iron content on well 15, but it was noted that the high iron content could be reduced by continued use.

Minor Aquifers

58. In addition to alluvial and Dakota aquifers, a number of minor aquifers have been tapped for smaller quantities of usually highly mineralized water. Some aquifers have not been used at Fort Carson, but nearby public and private landowners have used them as sources of water. Each aquifer is discussed and brief formation descriptions are provided for any aquifer not outcropping on Fort Carson (i.e. not covered in Part III).

Dawson Formation Aquifers[23,25]

59. The Dawson (Paleocene-Upper Cretaceous Series) is a multi-aquifer formation consisting of arkosic and andesitic units. The Paleocene arkosic unit averages 180 ft in thickness and is composed of alternating beds of fine to very coarse-grained arkosic sandstone, variegated claystone, siltstone, and shale; the beds are lenticular and differ in thickness and areal extent. The Upper Cretaceous andesitic unit contains andesitic sandstone, siltstone, and andesitic pebbles; it averages 200 ft in thickness. The aquifers are located in the arkosic unit and have been successfully tapped in areas north of Colorado Springs (e.g. the U. S. Air Force Academy wells discussed in Reference 25). Many of

the wells producing from the Dawson flow are under artesian pressure. The aquifers of the Dawson are recharged by precipitation and by streams where the beds outcrop. In addition to well flow, water is discharged from this formation by seeps and by evaporation where the aquifers are unconfined close to the ground surface. Six Dawson wells on the U. S. Air Force Academy had an average estimated capacity of 333 gpm after pumping 30 days in 1967. Although the yield could decline if the wells were pumped continuously for longer periods, the rate of decline would be small. The average hardness (calculated as $CaCO_3$), sulfate content, and iron content were 104.4 ppm, 54.9 ppm, and 0.01 ppm, respectively, which are considerably below the criteria accepted by the USPHS.[23]

Laramie - Fox Hills (L-F*) Aquifer[20,25]

60. Water-yielding sandstone beds in the upper part of the Fox Hills Sandstone and the lower part of the Laramie Formation (both Upper Cretaceous Series) constitute the L-F aquifer, which is confined above by thick intervals of relatively impermeable beds. Each formation is over 250 ft thick. The contact between the Fox Hills Sandstone and the Laramie Formation lies within this aquifer. The L-F aquifer can be divided into three units: the lowest unit, composed of fine- to medium-grained sandstone; the middle unit, composed of sandy shale interbedded with thin seams of coal; and the uppermost unit, composed of well-sorted fine- to medium-grained sandstone. This aquifer is recharged by precipitation and streams where the formations outcrop. The water moves downdip through the sandstone beds and is discharged by wells or by springs and seeps. Water is confined under artesian pressure by overlying beds of shale. Average estimated capacity of each of the three U. S. Air Force Academy L-F wells after 30 days of pumping was 100 gpm. The average hardness (calculated as $CaCO_3$), sulfate content, and iron content were 225.0 ppm, 142.0 ppm, and 0 ppm, respectively.

Niobrara Formation Aquifer[20]

61. At Fort Carson three windmill wells (1, 2, and 5) are probably tapping the Niobrara aquifer. Jenkins[20] states that possibly small

---

* Reference 25.

quantities of water can be obtained from wells drilled into the limestone beds of the lower part or into the sandy limestone beds near the middle of the formation. He also states that water obtained from this aquifer is usually of poor quality because of the mineral matter dissolved from the shale and limestone.

Lykins Formation Aquifer

62. Two wells at Fort Carson (11 and 12) appear to be producing from the Lykins. Little information is available on this aquifer. Jenkins and Hurr,[22] however, report a futile attempt to produce water from the Lykins; the well was abandoned as dry at a depth of 22 ft.

Fountain Formation Aquifer

63. One Fort Carson well (14) appears to be producing from the Fountain Formation. Little information is available on this aquifer except that Jenkins and Hurr[22] report four Fountain wells drilled in the proposed expansion areas of Fort Carson (Tract 202). They determined "aquifer yield pumping rate-casing storage values" on two of these wells, which, unfortunately, averaged only 2 gpm. Hardness ($CaCO_3$) averaged 187.5 ppm.

PART V: SEISMICITY

64. The measurement of the seismic impulses created by earthquakes, the seismic history, and the determination of potential earthquake hazards are keys to effective engineering and resource management. An examination of the methods used to measure earthquake intensity and a discussion of seismicity and its impact on engineering and resource management problems are presented below.

Measurement and Portrayal of Earthquake Intensity[26,27]

65. Seismic impulses created by earthquakes or other shocks can be measured directly with seismographs. These devices are capable of recording vibrations ranging from destructive earthquakes to slight tremors caused by winds, surf, storms at sea, or man's activities. The epicenter of an earthquake can be located approximately from the seismic records of a single station and more accurately from those of several stations. The precise time of occurrence of these shocks can also be determined from these records. Seismograph stations are located throughout the world, the greatest concentration being in those areas of greatest seismicity, such as California and Japan. In the United States, the seismological section of the U. S. Coast and Geodetic Survey (USCGS) provides rapid determination of earthquake epicenters.

66. In order to express either the size of an earthquake or its effect on the surrounding region, or to regionalize the potential hazards of future seismic disturbances, various scales and maps have been devised. The two most commonly used scales in the United States are the Richter Magnitude Scale and the Modified Mercalli (MM) Intensity Scale. Seismic risk maps are used to portray the relative intensity of earthquakes to be expected in any given region.

Richter Magnitude Scale

67. The Richter Magnitude Scale, developed by Charles F. Richter, is the most commonly used scale to express the relative size of earthquakes in terms of the total energy released as seismic waves. The

magnitude of an earthquake is defined in terms of the logarithm of the amplitude of the motion recorded on a standard seismogram at a distance of 100 km (62 miles) from the epicenter. The scale is expressed in Arabic numerals. It allows a quick instrumental determination of the size of an earthquake by seismographic methods. The Richter Scale uses numbers from 0 to 9. No recorded earthquake has yet reached 9, the largest being about 8.8. The San Francisco earthquake of 1960 was 8.3; the 1971 Los Angeles quake was "only" 6.6, but as the epicenter was relatively close to the metropolitan area, the local intensity was high. Within the immediate area of the epicenter, the limit of perceptibility without seismic instruments is about 2.0, and the threshold of potential damage is about 5.0.

MM Intensity Scale

68. The MM Intensity Scale (Table 2) is a subjective scale that arbitrarily measures earthquake effects from a particular shock observed at various locations within the affected or perceptible area. The scale is divided into twelve categories of ascending intensities, designated by Roman numerals. Table 2 lists the specific observable phenomena that appropriately distinguish each category. Damage to buildings varies so much with local soil conditions and, to some extent, with the building standards used that the value of this scale for comparing earthquakes in different countries is limited. When the scale is uniformly applied over a given area to describe the effects of an earthquake, it can be very useful.

Seismic risk maps

69. Seismic risk maps are used to portray intensity or damage that can be expected in a given area. Figure 9 is a seismic risk map of the United States, adapted from Reference 27. It is based on the "known distribution of damaging earthquakes and the MM Intensities associated with these earthquakes, evidence of strain release, and consideration of major geologic structure and provinces associated with earthquake activity."[27,28] It has been adopted by the USCGS and other government agencies. Fort Carson has been mapped as an area of minor expected damage.

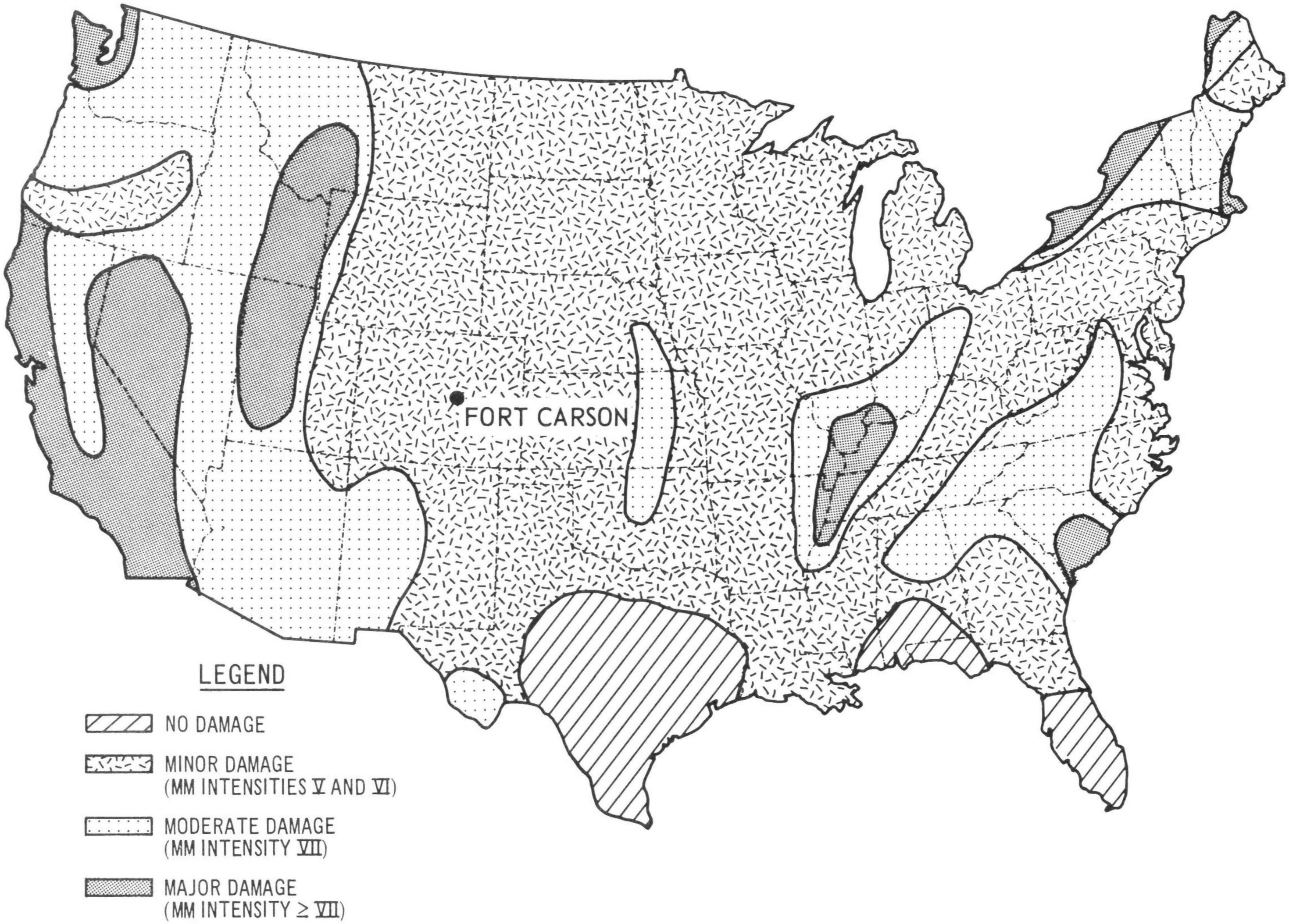


Figure 9. Seismic risk map of the United States (adapted from Oliver et al.[27])

Seismicity and Its Impact on Engineering and Resource Management Problems at Fort Carson

70. A brief review of the seismic history of Colorado and the impact of seismicity on engineering and resource management at Fort Carson are given in the following paragraphs.

Seismic history of Colorado

71. No destructive earthquakes have ever been recorded in Colorado, but from 1882-1946, six earthquakes of moderate to fairly strong MM Intensity (III-VII) were listed for the state. During the period 1947-1961, 14 light to moderate shocks were felt in Colorado. Two of the latter period originated in adjacent states. The epicenters of most of the others were located in northwest, southeast, and southwest Colorado. The maximum reported MM Intensity for the 1955 and 1960 shocks, in the Creede-Silverton-Ouray area, was VI. The tremors near Derby (Denver area), during the period June 1962 to February 1966, had reported MM Intensities also at a level of VI. Maximum recorded Richter Magnitude of earthquakes in Colorado is 4.3.

72. The Rampart Range Fault extends all along the base of Rampart Range. It is a fault of large displacement, which locally has brought Precambrian granites on the west into contact with the much younger (Tertiary) Dawson Arkose on the east. The fault apparently has long been inactive. Since no scarps have been observed in the alluvial deposits overlying the pediments, there has obviously been no significant movement in recent geologic time. Further, no seismic activity has been recorded on or related to this fault. Perhaps the most convincing evidence against the occurrence of intense tremors in this region during recent times is the abundance of balanced rocks, top-heavy pedestal rocks, and thin upright monumentlike erosional remnants. However, on the basis of known seismic shocks and history in other countries (e.g. Morocco) and the fairly strong tremors recorded in Colorado in recent years, earthquakes of destructive magnitude are a theoretical possibility in this region. Certainly, the presence of the Rampart Range Fault,

and related adjustment faults, in the Fort Carson area cannot be ignored.

73. The most recent earthquake investigation in Colorado is by Presgrave.[29] During a 7-2/3-year period (beginning in the late 1960's), he documented and analyzed all shocks occurring in Colorado, working from two stations, one in Bergen Park, Colorado (west of Denver), and another in Vernal, Utah. His first task was to separate actual earthquakes from man-made shots (such as those at a military arsenal). This was done by observing the locality of the epicenter, time of occurrence, and intensity. He then plotted the location of earthquakes, not at actual epicenters but at common areas of occurrence. Figure 10 shows the localities and number of earthquakes in central Colorado. The number "11" in the circle next to Colorado Springs, for example, is the total number of earthquakes detected in the Colorado Springs area. Presgrave's next step was to separate those earthquakes having a magnitude of $\geq$ 2.5 on the Richter Scale. In the same area of Colorado as covered by Figure 10, Figure 11 shows the number of earthquakes in the Colorado Springs area having a Richter Magnitude of $\geq$ 2.5 to be 4. He then statistically analyzed the earthquake data as shown in Figure 12, which gives maximum Richter Magnitudes of earthquakes having a probability of occurrence of 1 during a 30-yr period in central Colorado. According to these predictions, Colorado Springs has a probability of an earthquake with a magnitude of 3.7 occurring once in 30 years. Presgrave's findings indicate that southwest-central and northwest-central Colorado are most susceptible to serious earthquakes, while the Colorado Springs-Pueblo area (and, therefore, Fort Carson) are relatively less susceptible to serious earthquake damage.

Seismicity and engineering[16]

74. Among the more significant engineering problems in central Colorado are those associated with some of the geologic strata. These strata can cause serious foundation problems and weaken structures to such a degree that an earthquake of even a relatively low magnitude (e.g. 4.0 on the Richter Scale) can cause considerable damage. These problem areas are as follows:

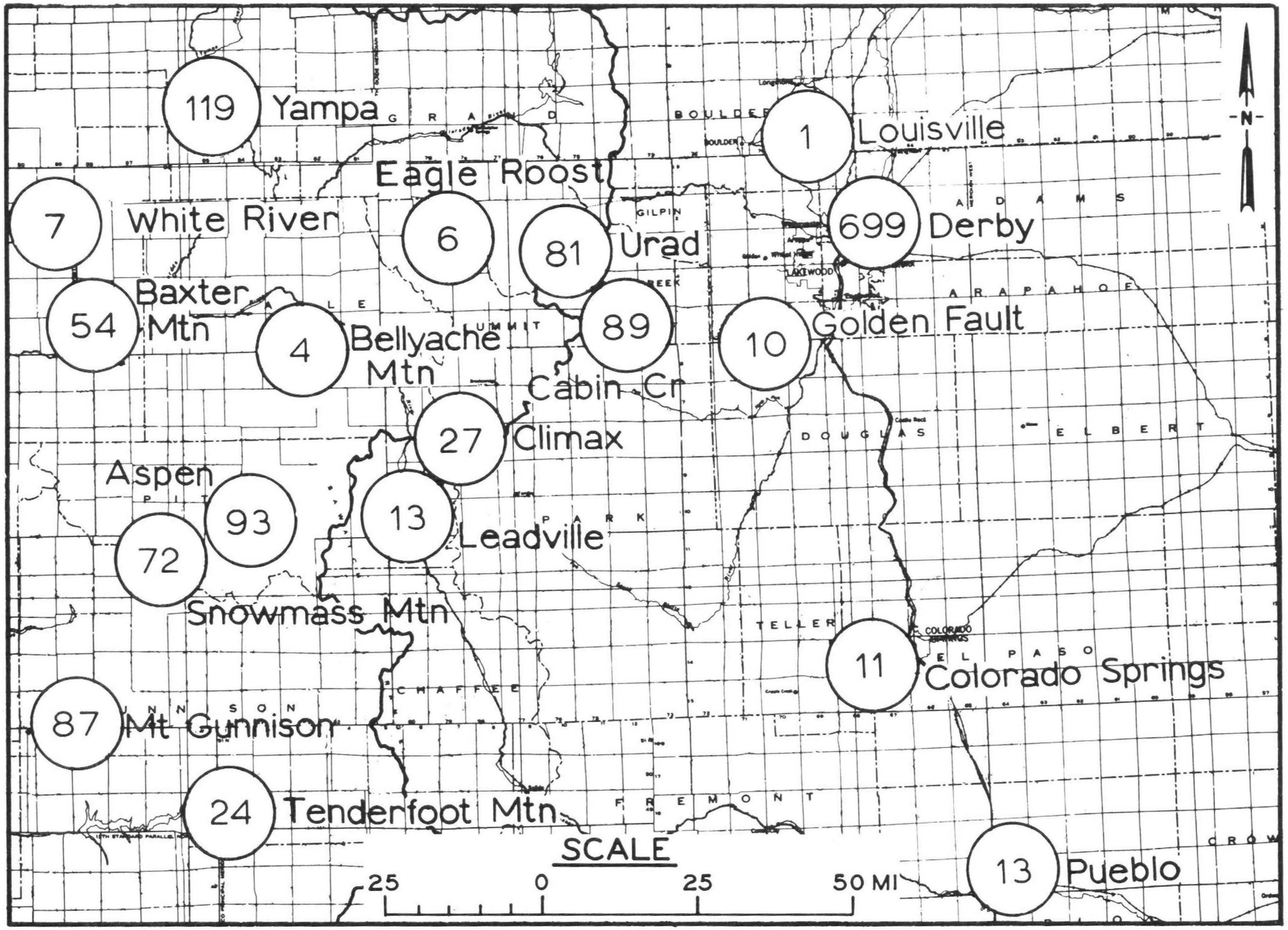


Figure 10. Total number of earthquakes in central Colorado detected during a 7-2/3-year period (adapted from Presgrave[29])

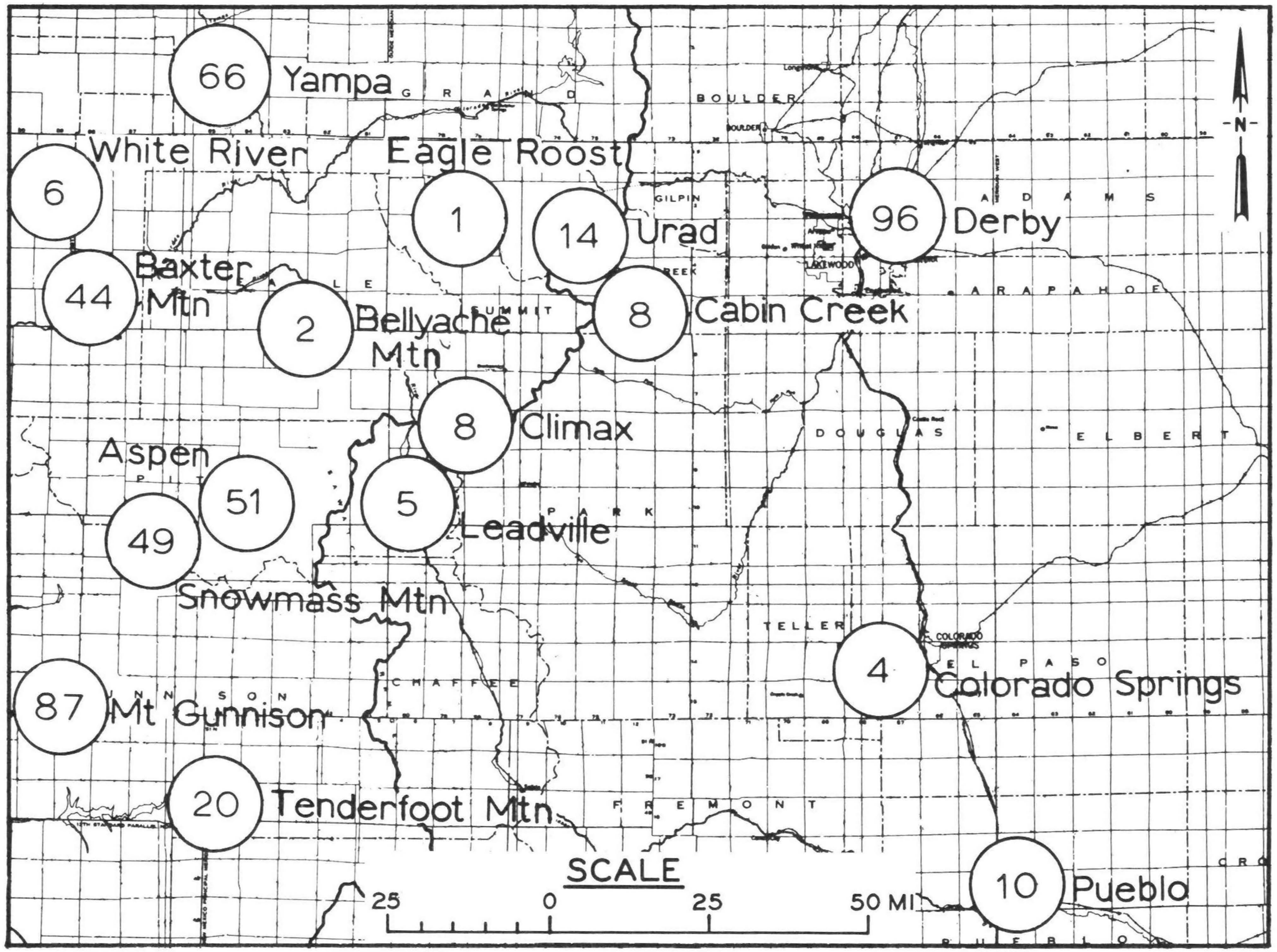


Figure 11. Total number of earthquakes having a Richter Magnitude of ≥ 2.5 detected during a 7-2/3-year period in central Colorado (adapted from Presgrave[29])

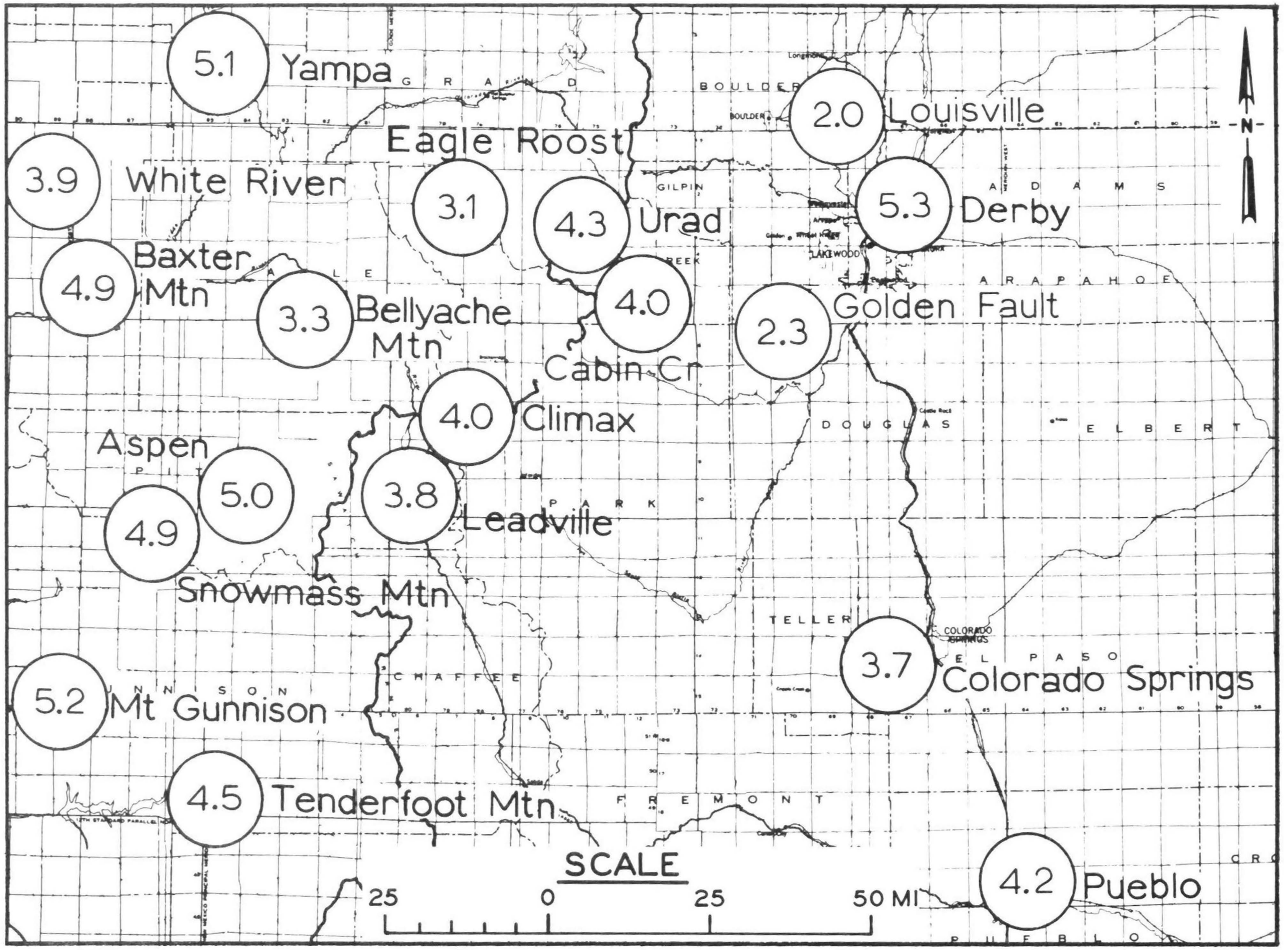


Figure 12. Maximum Richter Magnitudes of those earthquakes having a probability of occurrence of 1 during a 30-year period in central Colorado (adapted from Presgrave[29])

a. Bentonite beds (typical especially of the Pierre, Niobrara, Carlile, and Graneros). Their propensity toward extreme expansion, especially when exposed to percolating water, makes these beds hazards to construction. They cause foundations to be susceptible to damage from even minor earthquakes.

b. Sulfate-bearing waters (derived from sulfate compounds found in most of the geologic units). They react with hardened concrete and cause corrosion, spalling, and eventual complete disintegration of the concrete. Corrosion of concrete in structures can create a hazardous condition even if the structure is exposed to relatively low-magnitude seismic shocks.

c. Landslides. Some of these deposits may be subject to further sliding, and some slopes that have not yet failed may become unstable under adverse conditions (e.g. rapid changes in moisture content). All of these areas warrant detailed site investigation before they are disturbed by excavation or construction activities. The earthquake stability of existing slides and other unstable slope areas is rated as very poor.

The State of Colorado has no Seismic Safety Element Plan; therefore, no zoning restrictions or regulations related to seismic safety exist.[28] It is important to consider all potential earthquake hazards when building structures on Fort Carson. By eliminating these hazards and by reinforcing new construction, greater structural integrity can be achieved, and damage from earthquakes can be minimized or avoided.

Seismicity and natural resource management

75. The management of natural resources at Fort Carson is influenced to some degree by seismicity, especially where structures are involved. For example, earthen dams, though less prone to damage than concrete structures, can be affected by earthquakes. These dams have been built to impound water for various purposes and to serve as sediment catchment basins. Adequate planning and investigation of potential problems can result in many tangible and intangible benefits. The same logic used in any construction should be followed. Areas of bentonite beds and of landslides or potential landslides should be avoided.

PART VI: SUMMARY AND RECOMMENDATIONS

Summary

76. Physiography, geologic structure and stratigraphy, groundwater, and seismicity are all very important parameters that must be considered in land and resource management at Fort Carson. The effects of each are summarized briefly.

Physiography

77. Fort Carson lies in both the Great Plains and Southern Rocky Mountains physiographic provinces. The abrupt wall-like mountain front that rises to the west of Fort Carson and forms the boundary between the two provinces is the most outstanding physiographic feature of this area. The proximity of the Rocky Mountains causes a marked influence on climate, surface hydrology, and sedimentation at Fort Carson.

Geologic structure and stratigraphy

78. The Rampart Range was forced upward during the Laramide orogeny, the latest episode of Rocky Mountain building. Results of this activity are numerous north-south- and northwest-southeast-trending faults, anticlines, and synclines. Geologic structural features on Fort Carson can (a) be a source of potential seismic activity, (b) cause difficulties in locating groundwater and in correlation of subsurface geologic units, and (c) present problems in construction. Each geologic unit on the military reservation has a unique set of properties that must be considered in any engineering activity. Many units serve as sources of sand, gravel, or other construction materials.

Groundwater

79. Supplies of groundwater at Fort Carson are inadequate both in terms of quality and quantity. Fort Carson's cantonment area is supplied by the city of Colorado Springs. At present, the only aquifers yielding potable water in sufficient quantities are the various Quaternary alluvial deposits and the Dakota Sandstone.

Seismicity

80. Fort Carson and the Colorado Springs area of central Colorado

have been spared of serious earthquakes. During a 7-2/3-year period, Presgrave[29] reported 11 earthquakes in the Colorado Springs area, but only four of these had Richter magnitudes of ≥ 2.5. Designers of structures at Fort Carson should take into consideration the possibility of seismic disturbances. Bentonite beds, sulfate-bearing waters, and landslide deposits are hazards to construction and can make foundations susceptible to damage from even a minor earthquake.

Recommendations

81. Based on the findings of this study, it is recommended that:

a. A closer quantitative look be taken at physiography and its relation to climate (especially temperature and precipitation), hydrology, and sedimentation for all of Fort Carson by:

(1) Establishing several permanent meteorologic stations on Fort Carson, such as those operated by the WES during the past 2 years, in order to establish long-term climatic trends on the reservation. (Data for both the WES and NWS stations are discussed in Reference 6).

(2) Establishing a stream-gaging and sediment sample collection program for some of the major streams on Fort Carson. Repeated surveys should be made on permanent cross sections on major streams to determine changes in stream cross-sectional areas and locations of erosion-prone areas.

b. A thorough aquifer investigation be made on Fort Carson to determine groundwater potential, especially of the Dakota Sandstone and the alluvial aquifers. If sufficient sources of suitable quality groundwater are located on the reservation, then Fort Carson would become less dependent on outside sources.

c. Fort Carson implements a seismic safety code that would involve quality and selection of materials and techniques for all future construction, so that earthquake hazards can be minimized, thus ensuring sounder construction and more efficient use and management of resources.

REFERENCES

1. Headquarters, Fort Carson and 4th Infantry Division, FC and 4D Regulation 200-1, 1975, "Fort Carson Environmental Program," Fort Carson, Colo.

2. Fenneman, N. M., Physiography of Western United States, 1st ed., McGraw-Hill, New York, 1931.

3. American Geological Institute, Dictionary of Geological Terms, Doubleday, Garden City, N.Y., 1962.

4. Strahler, A. N., Introduction to Physical Geography, 2nd ed. Wiley, New York, 1970.

5. Visher, S.S., Climatic Atlas of the United States, Harvard University Press, Cambridge, Mass., 1972.

6. West, H. W. and Floyd, H. M., "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural Resources; Water-Quality, Meteorologic, and Hydrologic Data Collected with Automated Field Stations," Technical Report M-77-4, Report 2, Sep 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

7. Keown, M. P., Dardeau, E. A., Jr., and Kennedy, J. G., "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin," Technical Report M-77-1, Mar 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

8. U. S. Geological Survey, Water Resources Division, Water Resources Data for Colorado (published annually), U. S. Government Printing Office, Washington, D. C.

9. Rekas, A. M. B. and Kirk, W. L., "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural Resources; Inventory and Assessment of Current Methods Used for Rangeland Conservation and Restoration," Technical Report M-77-4, Report 3 (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

10. Keown, M. P. et al., "Literature Survey and Preliminary Evaluation of Streambank Protection Methods," Technical Report H-77-9, May 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

11. Clark, T. H. and Stearn, C. W., The Geological Evolution of North America; a Regional Approach to Historical Geology, Ronald, New York, 1960.

12. Scott, G. R., "Geology of the Northwest and Northeast Pueblo Quadrangles, Colorado," Miscellaneous Geologic Investigations Map 1-408, 1964, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

13. Scott, G. R., "Geological Map of the Pueblo, 1° by 2° Quadrangle, South-Central Colorado," MF-775, 1976, U. S. Department of the Interior, Geological Survey, Denver, Colo.

14. Scott, G. R. and Wobus, R. A., "Reconnaissance Geologic Map of Colorado Springs and Vicinity, Colorado," MF-482, 1973 (also Front Range Urban Corridor, Colorado, Environmental, Geologic and Hydrologic Studies No. 5), U. S. Geological Survey, Denver, Colo.

15. Varnes, D. J. and Scott, G. R., "General and Engineering Geology of the United States Air Force Academy Site, Colorado," Professional Paper 551, 1967, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

16. Scott, G. R., "General and Engineering Geology of the Northern Part of Pueblo, Colorado," Bulletin 1262, 1969, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

17. Grose, L. T., "Geological Formations and Structure of Colorado Springs Area, Colorado," in Guide to the Geology of Colorado, R. J. Weimer and J. D. Haun, eds., Geological Society of America, New York, N. Y. 1960, pp 188-195.

18. Darton, N. H., "Geology and Underground Waters of the Arkansas Valley in Eastern Colorado," Professional Paper No. 52, 1906, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

19. Major, T. J. et al., "Hydrogeologic Data for the Lower Arkansas River Valley, Colorado," Basic Data Release No. 21, 1970, U. S. Geological Survey, Colorado Water Conservation Board, and Southeastern Colorado Water Conservation District, Denver, Colo.

20. Jenkins, E. D., "Ground Water in Fountain and Jimmy Camp Creek Valleys, El Paso County, Colorado," Water Supply Paper 1583, 1964, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

21. U. S. Army Engineer District, Omaha, CE, "Ground Water Investigation, Camp Red Devil, Fort Carson, Colorado," 17 Oct 1967, Omaha, Nebr.; prepared by Woodward, Clyde, Sherard, and Associates, Denver, Colo., under Contract No. DACA 45-68-0018.

22. Jenkins, E. D. and Hurr, R. T., "Hydrologic Investigation, Fort Carson, Colorado Expansion Project, Project Civil Action 8920, Tract 202," Open Field Report, 1970, El Paso County, Colorado, U. S. Geological Survey, Denver, Colo.

23. U. S. Department of Health, Education, and Welfare, Public Health Service, "Drinking Water Standards," Publication No. 956, 1962, U. S. Government Printing Office, Washington, D. C.

24. U. S. Army Engineer District, Omaha, CE, "Geohydrologic Investigation, Proposed Camp Sites, Tables VII and VIII, Fort Carson, Colorado," 9 Feb 1968, Omaha, Nebr.; prepared by Woodward, Clyde, Sherard, and Associates, Denver, Colo., under Contract No. DACA 45-68-0039.

25. Cardwell, W. D. E. and Jenkins, E. D., "Ground Water," General and Engineering Geology of the United States Air Force Academy Site, Colorado, Professional Paper 551, 1967, U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C.

26. Zappi, M. A., "Seismic Risk," 1975 (unpublished), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

27. Oliver, J. A. et al., Part 1, Seismology Responsibilities and Requirements of a Growing Science, National Academy of Sciences, Washington, D. C., 1969.

28. Department of the Army, Headquarters, FORSCOM, "Draft Environmental Statement, Land Acquisition at Fort Carson, Colorado, Project No. 281000, Jun 1974;" prepared by Dames and Moore, Denver, Colo., for U. S. Army Engineer District, Omaha, CE, Omaha, Nebr., under Contract No. DACA 45-74-C-0078.

29. Presgrave, B. W., The Seismicity of Colorado, Master's Thesis (in preparation), Department of Geophysics, Colorado School of Mines, Golden, Colo.

Table 1

Locations of Downrange Wells on Fort Carson

Well No.	Location (Military Grid Coordinates)	Probable Aquifer	Well Depth m	Comments
1	08145249	Kns	51	Windmill
2	10545452	Kns	43	Windmill
3	08485514			Windmill
4	05905632	Kc	103	Windmill
5	21665645	Kns	85	Windmill
6	14335852			Windmill
7	03686019	Kdp	53	Windmill
8	07196092	Kdp	93	Windmill
9	05746193	Kdp	96	Windmill
10	10966257			Windmill
11	09496479	TR Pl	72	Windmill
12	10626704	TR Pl	58	Windmill
13	05716888			Windmill
14	09897169	PPf	58	Windmill
15	20945438	Kdp	165	Well with electric pump, Tank Table VIII
16	16775683	Kdp	245	Well with electric pump, Tank Table VII
17	15957397			Well with electric pump
18	07766104	Kdp	103	Well with electric pump, Camp Red Devil

Table 2

Modified Mercalli Intensity (Damage) Scale of 1931

(Abridged)

I.	Not felt except by a very few under especially favorable circumstances.
II.	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated.
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.
V.	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed.
VI.	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII.	Damage total. Waves seen on ground surface. Line of sight and level distorted. Objects thrown upward into the air.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Dardeau, Elba A
Environmental baseline descriptions for use in the management of Fort Carson natural resources; Report 5: General geology and seismicity / by Elba A. Dardeau, Jr., Marcos A. Zappi. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
55, [2] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-77-4, Report 5)
Prepared for Directorate of Facilities and Engineering, Fort Carson, Colorado, and Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A162121A896, Task 01, Work Unit 006.
References: p. 53-55.
1. Environmental data. 2. Environmental management. 3. Fort Carson, Colo. 4. Geology. 5. Military installations. 6. Natural resources. 7. Seismicity. I. Zappi, Marcos A., joint author. II. Fort Carson, Colo. Directorate of Facilities and Engineering. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; M-77-4, Report 5
TA7.W34 no.M-77-4 Report 5