GEOLOGIC FACTORS IN THE EVALUATION OF WATER POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES

by

L. K. Burns
D. R. McCrumb
S. M. Morrison

December, 1973

ENVIRONMENTAL RESOURCES CENTER

Colorado State University
Fort Collins, Colorado

Completion Report Series
No. 54

GEOLOGIC FACTORS IN THE EVALUATION OF WATER POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES

by

Lary K. Burns
Dennis R. McCrumb

Department of Earth Resources

and

S. M. Morrison

Department of Microbiology

Colorado State University

December, 1973

The work upon which this report is based was supported by the Colorado Water Quality Control Commission pursuant to Agreement No. 87-194-2, and supplements Project B-023-Colo supported by funds provided by the United States Department of the Interior, Office of Water Resources Research, as authorized by the Water Resources Research Act of 1964, and pursuant to Grant Agreement No.(s) 14-01-001-1882.

Colorado Water Resources Research Institute
Colorado State University
Fort Collins, Colorado 80523

Norman A. Evans, Director

ABSTRACT

GEOLOGIC FACTORS IN THE EVALUATION OF WATER POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES

In order to establish the relationship between the geologic setting and the occurrence of water pollution in mountain home developments containing individual sewage disposal systems, three areas in Colorado's Front Range were studied. Two of the areas were known to have biological contamination as confirmed by microbiological tests. Also, each area had adequate rock exposures to allow for detailed geologic study, the absence of thick soil profiles above bedrock and current development for mountain home location. In addition, each of the selected study areas differed in geologic setting, age of development and home density in the development. The extent of water pollution was established by a program of well and surface water testing for total coliform. Fecal coliform and inorganic contaminants were tested in selected wells.

Detailed geologic maps were made of each area to locate features such as dikes or shear zones which might act as either barriers or conduits to ground water movement. Slope maps were prepared for the area by computer plots of digitized data of elevations taken from U.S. Geological Survey topographic maps. Determination of the water table profile and extent of alluvial fill in valley bottoms was

accomplished using driller's well logs for each well in the area. In addition, soils were tested to determine their effective grain size, a joint and foliation study was conducted to determine the direction of pollutant travel should effluent enter these openings, driller's well logs were used to establish depth of soils and depth of weathering in bedrock and data from county health records were used to establish soil percolation rates.

Data were compiled in the form of overlays on base maps of the areas involved. A topographic map with the geologic overlay was used in conjunction with various combinations of the field derivitive overlays to indicate the pollution potential for specific areas. The overlays used in this procedure were compiled from the following parameters: 1) slope, 2) depth of soil, 3) depth of intensely weathered bedrock, 4) local water table profile, and 5) soil percolation rates. These overlays indicated that the Glen Haven area is unsuitable for soil absorption sewage systems because of steep slopes, soil depth and depth of the water table. Most of the Tall Timbers area was indicated as unsuitable for soil absorption systems because of slope, soil depth and local geology. The Crescent Park area was categorized as safe (in part) for soil absorption systems, however, local areas within the subdivision were categorized as hazardous.

From the results it was suggested that a procedure such as the one used in this study could be used for each subdivision proposed in the mountainous regions of Colorado. Thus more effective use of mountainous areas might be possible while maintaining a low probability of ground water contamination. Areas within each proposed subdivision would be classified as safe, hazardous, or unsuitable for soil absorption sewage systems. Unsuitable areas could be used as parks or greenbelts, hazardous areas would have low population densities and safe areas would be allowed to have higher population densities as long as other factors were favorable. In addition, procedures such as the one used in this investigation could be used to indicate mountain areas which should require a municipal sewage disposal system before development to ensure that the ground water system was not polluted.

PREFACE

The authors thank R. B. Johnson and R. S. Parker of the Department of Earth Resources for their cooperation and assistance. Ron Stow of the Department of Microbiology made the analyses for bacteria reported in this paper, and R. Giffin assisted in certain statistical and computer analyses of the data. Comments by R. B. Johnson improved the manuscript. The cooperation of the Jefferson, Boulder and Larimer County Health Departments is gratefully acknowledged. Special appreciation is due the residents of the areas covered in this study for their cooperation; without which the study could have not been completed.

This research was supported (in part) by the State of Colorado, Water Pollution Control Commission of the Department of Health by a Special Study Grant No. 31-1873-0129.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

Scope and Purposes of the Project

The general problem that is considered in this project is that of the pollution of ground water supplies in mountain areas by dispersal type sewage disposal systems as developmental pressure on mountain areas increases. The increase in population in the mountainous areas of Colorado has produced serious problems concerning the protection of the environment and one of the most pressing problems at present is that the use of individual dispersal-type sewage disposal systems, usually of the leach field-septic tank type, in areas unsuited for this type of system is causing a deterioration in the quality of ground water supplies and to some extent surface water supplies as well.

The magnitude of the problem cannot be accurately known with data now available, but records of Jefferson, Boulder and Larimer County Health Departments indicate that the percentages of well water samples from mountainous areas tested in 1971 that were unsafe ranged from 20 to almost 40 percent, depending on County. Although these figures must be used with extreme caution since many water samples are tested only when there is reason to believe they may be contaminated and some contaminated supplies are tested several times further biasing the statistics, the clear indication that serious water pollution is already present cannot be rejected.

One of the primary purposes of this project is to establish the relationship between the geologic setting and the water pollution potential in mountainous areas that currently have or are likely to have homes or other dwellings built which use dispersal-type sewage disposal systems. Another primary purpose of the study is to devise a method to evaluate the probability that water pollution in a given mountainous area will occur if that area is developed. This method of evaluation can be utilized for land-use planning with respect to water quality preservation.

At the onset, the authors of this report warn that many of the conclusions must be held as tentative until tested thoroughly by both those who agree and disagree with them. Such a testing is invited. In fact, we have deliberately decided to put forth conclusions and ideas even though they may be tentative in order to encourage a thorough testing and discussion of our ideas. The justification for such an approach is the urgent need for revised and scientifically sound regulations concerning mountain water and sewage regulations.

As only three mountain developments were used in this study, it may be that some of the conclusions are not generally applicable; however, we believe the basic approach to be valid in spite of the limitations of this approach. Other limitations encountered in the study include the reliability of certain data collected, especially that from other sources. The specific nature of these limitations is discussed in the Summary.

Specific Objectives

One of the more specific objectives of the study is to determine what geologic and geomorphic parameters influence the effectiveness of disposal-type sewage disposal systems. The parameters that were considered include bedrock type and mineralogy, jointing in bedrock, depth of weathering of bedrock, soil depth, slope, depth of ground water table, proximity to special geologic features such as faults, shear zones and igneous dikes, clay mineralogy of the soil, effective grain size of the soil, and percolation rate of the filtering material. The determination of the effect of a combination of single parameters on the potential for a dewage disposal system to pollute the ground water was also a prime objective of the study.

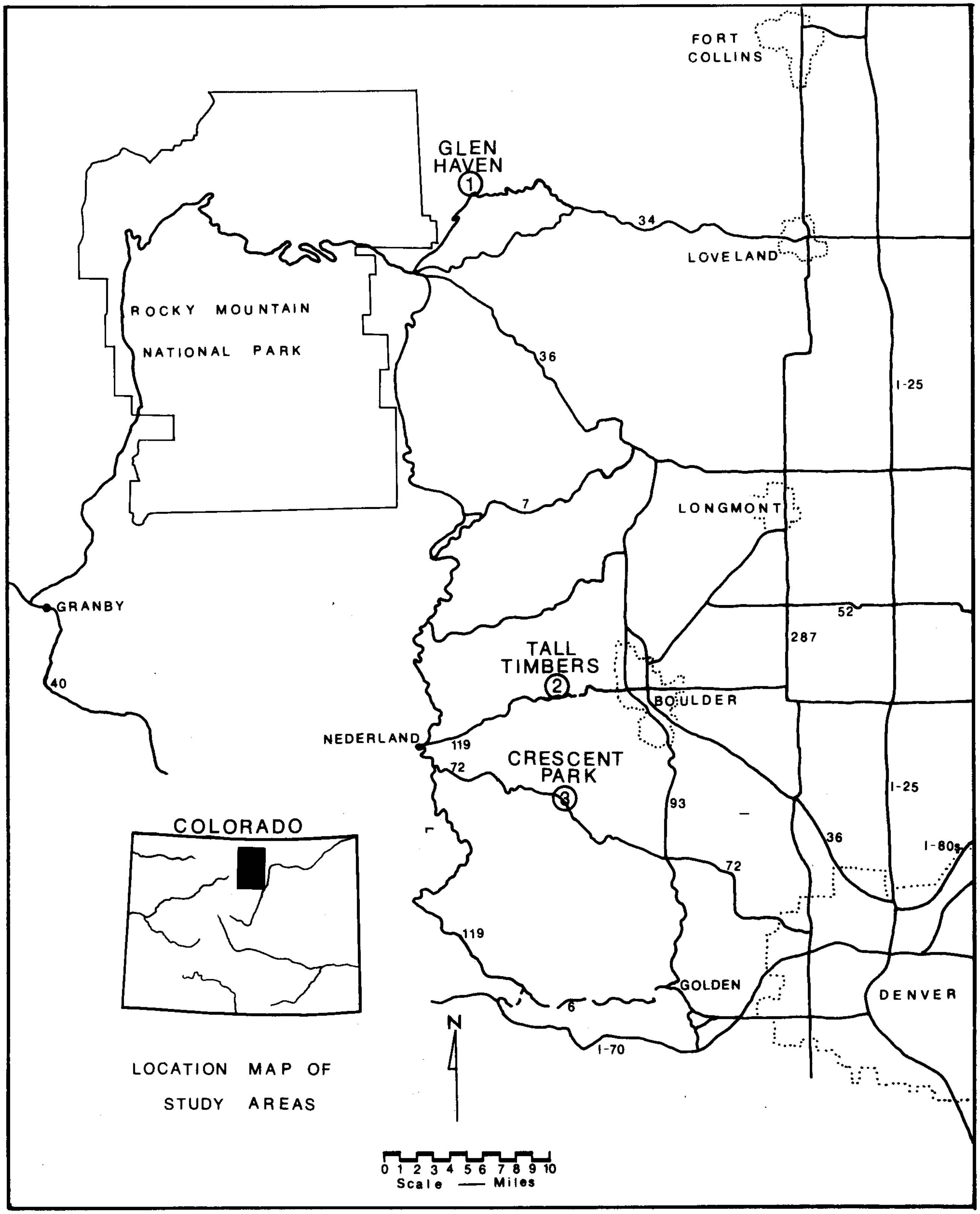
Another specific objective was to devise a method whereby relatively easily obtainable quantitative data on important parameters could be used in a system to evaluate the pollution potential in a given area, such as a housing development or proposed development area. Such a method would allow a qualified engineer, geologist, soil scientist or technician to use the data about the important geologic and geomorphic parameters to evaluate an area with respect to pollution potential and aid in development reasonable waste disposal densities to population density ratios that would not be likely to cause pollution of the ground and surface waters in the area. Such a land-use planning tool would be of help in the prudent development of Colorado's mountainous areas.

Location of Study Areas

Three sites are studied in detail in this report. Two sites were chosen because they met the requirements of having good geologic controls, shallow or no soil in at least part of the area, and documented water pollution. The third site, Cresent Park, did not show any significant pollution and was used as a control area.

Site 1 is the community of Glen Haven, located approximately seven miles northeast of Estes Park, Colorado, in sections 27 and 34 of Township 6 North, Range 72 West, Larimer County. Site 2 is the Tall Timbers development in Boulder County, located five miles west of Boulder, Colorado, just north of Boulder Canyon on County Road No. 122, in section 33 of Township 1 North, Range 71 West. Site 3 is the Crescent Park subdivision located approximately five miles west of the junction of Colorado highways 93 and 72, up Coal Creek Canyon in the northern part of Jefferson County, section 4, Township 2 South, Range 71 West. The location of these sites are shown on Figure 1.

FIGURE 1. Location map of study areas.



LOCATION MAP OF STUDY AREAS

LITERATURE

Recently there has been an increasing interest in the problem of contamination of shallow ground water systems. This has resulted in several research projects on various aspects of ground water contamination. The extent of ground water pollution in mountainous areas is indicated by records from county health departments of some counties along Colorado's Front Range. Jefferson County records show that about 20 percent of the water samples tested by their county health department in 1971 were considered unsafe and, in neighboring Boulder County almost 40 percent of the water samples tested by their health department in 1971-72 were considered unsafe. These figures are biased, because many water samples are tested only when there is reason to believe they may be contaminated and in some cases the same water supply is tested several times after pollution has been detected. However, they do indicate that there are pollution problems in these counties. In addition, Millon (1970) has demonstrated that certain areas in Colorado's Front Range have reached the point where their ground water system is contaminated to the extent that it may not be possible to reclaim the aquifer. Data reported from the current investigation indicate that of three areas studied, one has 28 percent of its wells polluted, a second area has almost 45 percent of its wells polluted and the third area 6 percent.

Allen and Morrison (1973) have shown that insufficient microbial filtration of leach field effluent occurs in and along bedrock fractures and joints as compared to that in soils. In addition, the distance was in excess of 100 feet and most probably exceeded several hundred feet.

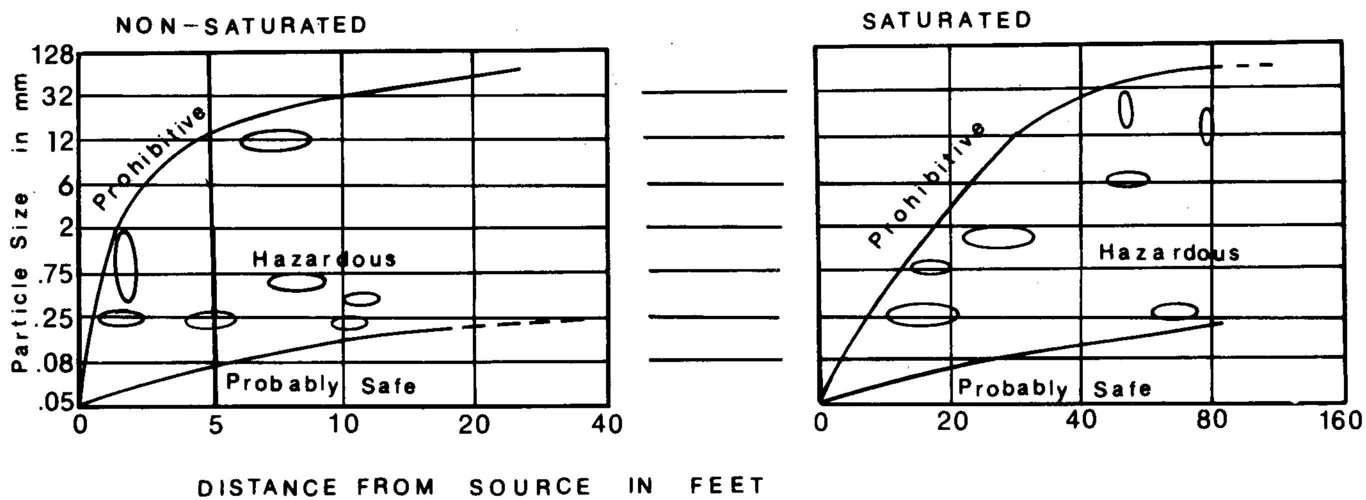
Franks (1972) has shown that a leach field system constructed in fractured rock will function properly for a year or two but then fail. This failure may be caused by plugging from suspended solids in the fractures or by anaerobic growth in the fractures. In addition to this, physical location is very important in the operation of leach field systems. Franks (1971) lists the following causes of failure to leach field systems due to improper physical location:

1) construction of leach field systems on slopes exceeding 20 percent,
2) location of leach field systems near construction cuts such that there is less than 15 feet of soil horizontally between the ground surface and the bottom of the leaching system,
3) construction of leach field systems in open gravel areas with a high water table,
4) construction of leach field systems on bedrock fractures which do not provide filtration or treatment of effluent, and
5) construction in surficial pervious deposits over nonwater bearing rocks which may result in downstream surfacing of fluid.

Other studies have shown that the nature of the soil used as the filtration media plays a dominant role in the subsequent life and travel of bacteria (Orlob and Krone, 1956; Romero, 1970, p. 43). In fact, the particle size of the filter material and whether or not the material is saturated can be used to determine the approximate distance effluent must travel to become properly filtered (see Figure 2) (Orlob and Krone, 1956, p. 32).

Freethy (1969) has shown that it is possible, at least to some extent, to determine the pollution potential of an individual well due to bacterial movement along joints and fractures from nearby leach fields.

FIGURE 2. Biological pollution travel in non-saturated material and with ground water in saturated material. The graphs show the sizes of filter material particles that are effective or ineffective in treating septic tank effluent in a leach line system. After Franks, 1972 and Romero, 1970.



NON-SATURATED
SATURATED
Particle Size in mm
128
32
12
6
2
.75
.25
.08
.05
Prohibitive
Hazardous
Probably Safe
0
5
10
20
40
0
20
40
80
160
DISTANCE FROM SOURCE IN FEET

METHODOLOGY

For this investigation all of the selected study sites were located on the eastern slope of Colorado's Front Range. It is in this area that land development is proceeding at a very rapid pace and thus the quality of the ground water is threatened. Because the objectives of this project included the analysis of tracts of land for land-use planning, two sites were selected from areas of known ground water pollution and a third was selected as an example of an area with no pollution. Each of the three study sites met the following requirements:

1) sufficient exposures of bedrock to allow for detailed geologic sampling and study,
2) the lack of a thick soil profile in at least part of the area, and
3) current or potential development of the area for mountain home sites.

In addition to the above requirements, each of the selected study sites differed in geologic setting (i.e. bedrock mineralogy and the occurrence and distribution of various geologic structures such as dikes and faults), age of development, home density and construction practices for homes, wells, leach fields, privies and roads.

Each area was studied in detail to include geology, soil analysis for effective grain size and clay mineralogy, extent and depth of weathered bedrock and the hydrologic characteristics of the ground water. Several geomorphic parameters and non-geologic parameters were also studied to relate their effect on the ground water system. These included slopes, drainage characteristics, ground water characteristics, age of development, type of sewage disposal systems, kind and depths of wells and home density.

Laboratory studies were used to augment field investigations and included:

1) Sieve analysis of soils to determine their texture,

2) X-ray analysis of clays present in soils and as weathering products and

3) Petrographic analysis of bedrock to determine mineralogy.

These were performed to determine the relative homogeneity of each study area.

Local Water Quality

A preliminary sampling program along Colorado's Front Range indicated that Glen Haven and Tall Timbers had significant levels of ground water pollution. During this preliminary sampling *Escherichia coli* (*E. coli*) had been detected in several well samples from both areas. In addition, the surface water samples from the Glen Haven area had shown positive tests for *E. coli* at each location sampled.

No positive tests for *E. coli* on the water samples from the Crescent Park area were detected in this preliminary sampling, and the area was selected for detailed study as an example of an area with low pollution. The Crescent Park area is similar to the other selected study sites with respect to the regional geologic and hydrologic conditions. It was felt that the Crescent Park area could be used as a control area.

Water quality in each of the areas was determined from both chemical and biological tests. Chemical tests included those for phosphates, detergents, nitrites, nitrates, and total dissolved solids as determined by conductivity. Biological tests were performed to determine total coliform. Fecal coliform was tested in selected wells. Total coliform was used as an indicator of pollution and was determined by the membrane filter technique. A sample was designated as unsafe when the arithmetic mean coliform density of a standard sample exceeded one per 100 ml (Walton, 1970). Water sampling was carried out over the period from July to December 1972. All water testing was performed in the water quality laboratory at the Microbiology Department of Colorado State University by Ron Stow. The complete results of the water quality for each area are presented in Appendix 1 and summarized in Table 1.

From the water quality results each well was categorized as either safe, a pollution indicator, or a variable pollution indicator.

TABLE 1. Summary of water quality test results in percent. Calculated as percent of pollution indicators and variable pollution indicators to the total number of wells sampled during July to December, 1972.

CRESCENT PARK	- 37 wells sampled 3 variable pollution indicators 0 pollution indicators 8.1 Percent wells with probable pollution
TALL TIMBERS	- 39 wells sampled 5 variable pollution indicators 6 pollution indicators 28.2 Percent wells with probable pollution
GLEN HAVEN	- 29 wells sampled 8 variable pollution indicators 5 pollution indicators 44.8 Percent wells with probable pollution

Wells were categorized as safe if the mean coliform density of all standard samples examined per month was less than one per 100 ml, pollution indicators were those wells where the mean coliform density was consistently over one per 100 ml (i.e. unsafe), and variable pollution indicators were those wells which received both safe and unsafe tests during the period of the sampling program.

Soil Analyses

Studies have shown that the texture of a soil or filter medium is more important than the permeability in removal of bacteria (Franks, 1972, p. 198). Soil texture can be indexed by the effective grain size, i.e. the grain size where 90 percent is coarser and 10 percent finer by weight (Franks, 1971). Romero (1970) stated that the aquifer material best suited for removal of biological contaminants were those that were uniformly composed of very fine to fine-grained sand with a high clay content. For these reasons textural and x-ray analysis of the soils present in each area were made. The x-ray analyses were performed to determine the clay types within the study areas. It was noted from soil maps prepared by the U.S. Soil Conservation Service that soil types were classified by slope and depth as well as other criteria. Thus in each study area soils were collected from valley bottoms, side slopes, and hill crests to determine if any variations in texture or clay mineralogy occurred. From the three areas a total of 32 soil samples were collected from 15 different locations. Plate 1, 8, and 15 are maps of each study area showing the locations of soil samples, bedrock samples, well locations, and stream sample locations. The data pertaining to soil analysis are in Tables 2 and 3.

Soil Sampling

A truck-mounted hydraulic auger and soil corer provided by the Agronomy Department of Colorado State University was used to collect the soil samples. Samples were taken from depths of three feet and six feet except when bedrock was encountered prior to that. In these locations samples were taken at bedrock depth. Each sample was collected using a punch tube core barrel when moisture content permitted. For dry powdery soils, the samples were taken directly from the auger blades.

A description of the soils was made during sample collection which included soil type, depth, and any bedrock encountered. The Crescent Park and Glen Haven areas have not been mapped by the U.S. Soil Conservation Service. Prior to the laboratory testing each sample was stored in cardboard containers and allowed to air dry. A sieve analysis was performed after each sample had been disaggregated by hand crushing. Care was taken to produce no additional fines during the analysis. Sieve sizes ranged from .50 mm to .044 mm in half phi intervals. After sieving for approximately 20 minutes the amount of soil in each sieve was weighed and recorded. The soil portion less than .044 millimeters was saved for clay separation. In addition, the sieve interval containing the effective grain size was determined from cumulative weight percents of each sample. The sieve analysis data is contained in Table 2 for all study areas.

X-ray Analysis

The clay sized portion of each soil sample was prepared for x-ray analysis using the following procedure developed by Ganow (1969). The soil portion less than .044 millimeters was suspended in approximately 500 ml of distilled water and allowed to stand for several hours while the clay fraction separated from the silt. This clay-silt mixture was then remixed and centrifuged at 1000 rpm for two minutes in an International No. 2 centrifuge. This left the clay sized material (less than .002 mm) in suspension and the silt sized material sedimented at the bottom of the beaker. The clay water suspension was then siphoned off and the procedure repeated to remove as much clay as possible. The silt sized portion was placed in a small beaker and oven dried to remove all the water. This material was then weighed and the percentage of silt determined. The approximate percent of clay in each soil sample was then calculated as the difference between the total sample weight and the sum of each portion in the sieve analysis plus the weight of the silt.

The following procedure for obtaining an oriented clay mount suitable for the treatments necessary in x-ray diffraction of clays is after Ganow (1969). Porous ceramic tiles approximately 1/16 inch thick were used as mounts. The clay water suspension which was siphoned off after centrifuging was concentrated to approximately 20 ml. About 10 ml of the clay-water mixture was allowed to drip slowly from a pipette onto the tile which was being subjected to vacuum pressure on the reverse side. This procedure was repeated until the tile was completely covered by clay sediment. The tile was then air dried in preparation for x-ray analysis.

Following the method of Carroll (1970) each tile was x-rayed after being subjected to the following treatments:

1) after reaching stability (approximately 48 hours) in an atmosphere of 50 percent relatively humidity,
2) after being subjected to an atmosphere of ethylene glycol vapor for a minimum of 24 hours,
3) after a one hour heat treatment of 300° C., and
4) after a heat treatment of 550° C. for one hour.

The diffraction scan following each of the above treatments was from 4° to 26° 2θ (two theta). The various clays present were determined from the combined diffraction patterns for each sample and are listed in Table 3. In addition, representative diffraction patterns were reproduced from several clay scans and can be found in Figures 4, 5, and 6, with the major peaks labeled as to the mineral which caused them.

FIGURE 3. Histograms of effective grain sizes for soils in each of the study areas.

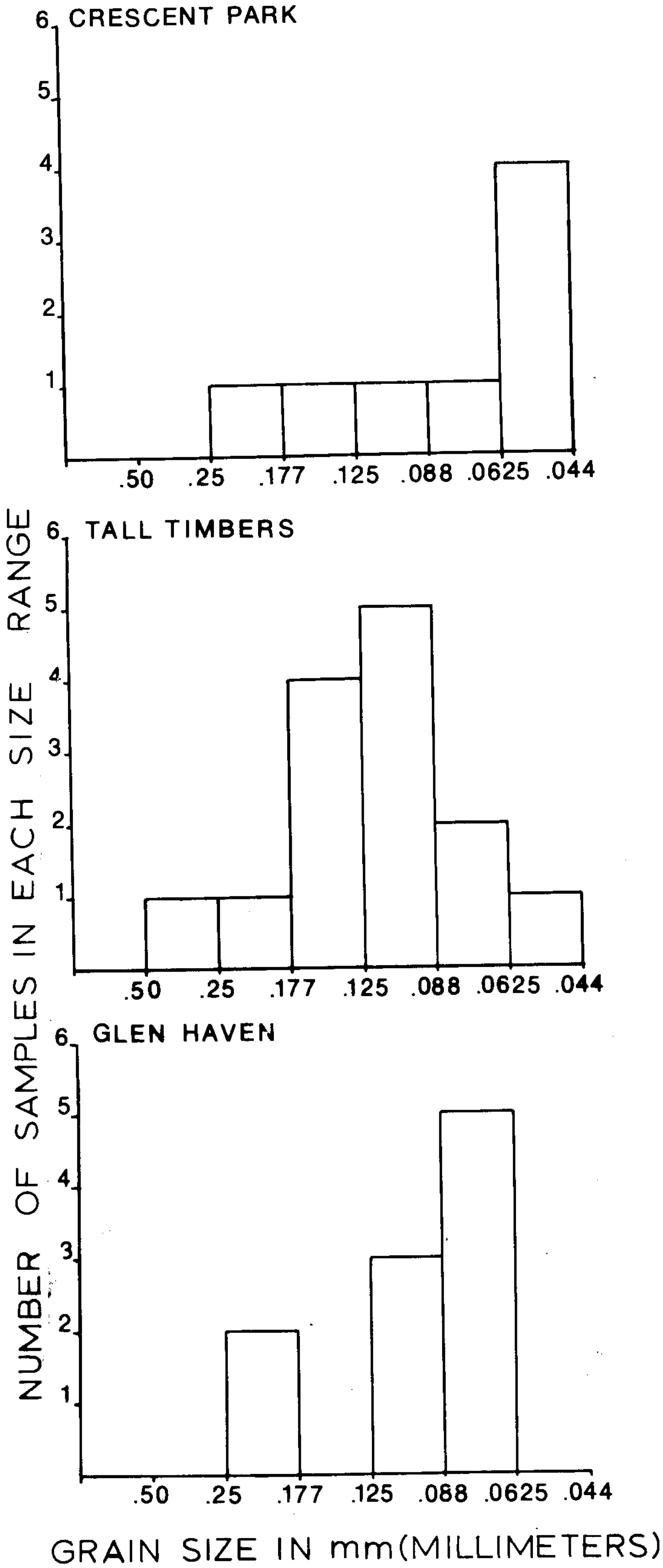

CRESCENT PARK
TALL TIMBERS
GLEN HAVEN
6
5
4
3
2
1
.50 .25 .177 .125 .088 .0625 .044
NUMBER OF SAMPLES IN EACH SIZE RANGE
GRAIN SIZE IN mm(MILLIMETERS)

TABLE 2. Sieve analysis of soil samples. Top line indicates weight percent of each sieve size, bottom line indicates cumulative weight percent.

d-90 = range of effective grain size
cb = sample collected with core barrel
a = sample collected from auger blades

Sample Number	Sieve Sizes in Millimeters .50	.25	.177	.125	.088	.0625	.044	Clay Silt	d-90	Percent Clay	Sample Depth Ft.	Method of Collection
							TALL TIMBERS					
1	64	13	4	6	3	2	2	5	.125-.088	.29	3.0	cb
	64	77	81	87	90	92	94	99				
2	69	10	4	4	3	3	1	6	.088-.0625	.27	6.5	cb
	69	79	83	87	90	93	94	100				
3	53	15	5	6	4	3	3	10	.044-.clay	.30	3.0	cb
	53	68	73	79	83	86	89	99				
4	58	15	6	5	4	4	2	6	.088-.0625	.24	5.0	a
	58	73	79	84	88	92	94	100				
5	56	14	5	6	4	3	3	9	.0625-.044	.31	6.0	cb
	56	70	75	81	85	88	91	100				
6	57	18	6	6	4	4	1	4	.125-.088	.27	1.5	a
	57	75	81	87	91	95	96	100				
7	66	16	4	5	3	2	2	2	.177-.125	.03	3.0	cb
	66	82	86	91	94	96	98	100				

TABLE 2. (continued)

Sample Number	.50	.25	.177	.125	.088	.0625	.044	Clay Silt	d-90	Percent Clay	Sample Depth Ft.	Method of Collection
	Sieve Sizes in Millimeters											
									TALL TIMBERS (cont.)			
8	57	20	6	5	4	3	1	4	.125-.088	.03	6.0	cb
	57	77	83	88	92	95	96	100				
9	73	14	4	4	2	1	1	1	.25-.177	-	3.0	cb
	73	87	91	95	97	98	99	100				
10	57	18	6	7	3	2	2	4	.125-.088	.17	6.0	cb
	57	75	81	88	91	93	95	99				
11	47	19	7	6	6	5	2	8	.088-.0625	.58	3.0	a
	47	66	73	79	85	90	92	100				
12	60	15	5	4	4	4	2	7	.088-.0625	.31	6.0	a
	60	75	80	84	88	92	94	101				
13	62	12	4	5	3	3	3	8	.0625-.044	.23	3.0	cb
	62	74	78	83	86	89	92	100				
14	61	14	5	5	4	3	2	6	.088-.0625	.33	6.0	cb
	61	75	80	85	89	92	94	100				

TABLE 2. (continued)

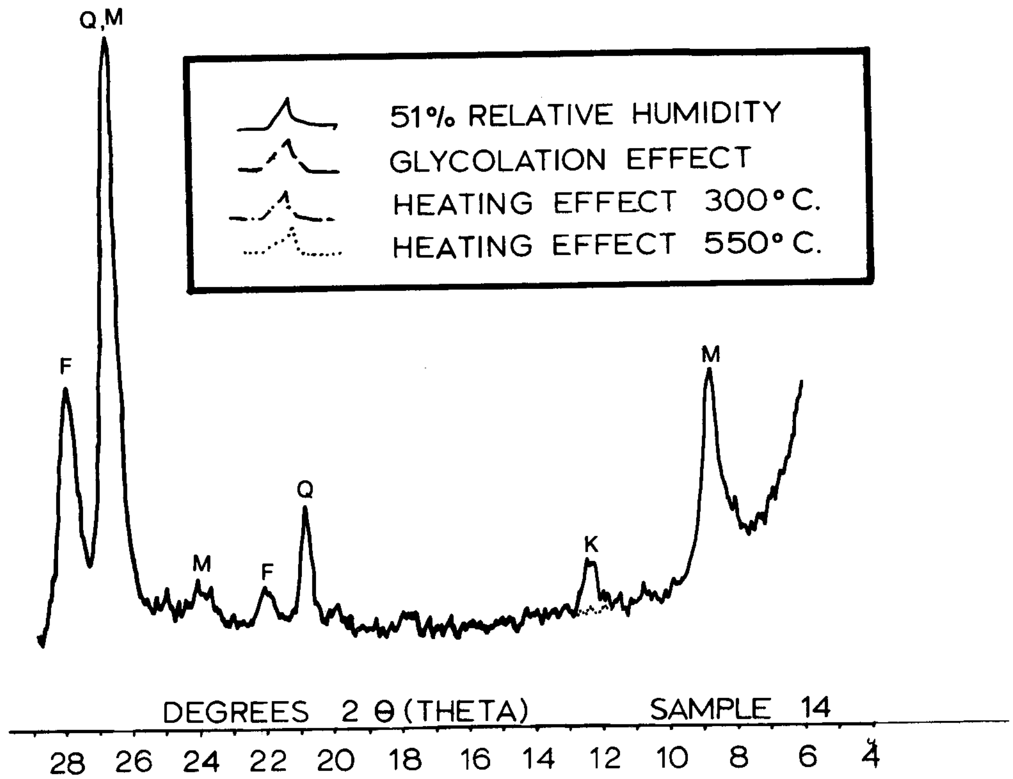
Sample Number	.50	.25	.177	.125	.088	.0625	.044	Clay Silt	d-90	Percent Clay	Sample Depth Ft.	Method of Collection
	Sieve Sizes in Millimeters											
								CRESCENT PARK				
15	69	14	4	5	2	2	2	3	.177-.125	.04	3.0	cb
	69	83	87	92	94	96	98	102				
16	64	14	5	4	4	3	1	5	.125-.088	.13	6.0	cb
	64	78	83	87	91	94	95	100				
17	57	14	6	6	3	3	3	9	.0625-.044	.45	3.0	cb
	57	71	77	83	89	92	101					
18	45	17	7	7	6	5	2	12	.044-.002	.43	5.0	a
	45	62	69	76	82	87	89	101				
19	41	21	8	9	4	3	3	11	.044-.002	.39	3.0	a
	41	62	70	79	83	86	89	100				
20	32	24	9	10	5	3	4	13	.044-.002	.44	4.2	a
	32	56	65	75	80	83	87	100				
21	47	14	6	7	4	3	4	16	.044-.002	.40	3.5	a
	47	61	67	74	78	81	85	101				
22	51	19	7	6	5	4	1	8	.088-.0625	.16	6.0	a
	51	70	77	83	88	92	93	101				

TABLE 2. (continued)

Sample Number	.50	.25	.177	.125	.088	.0625	.044	Clay Silt	d-90	Percent Clay	Sample Depth Ft.	Method of Collection
	Sieve Sizes in Millimeters											
							GLEN HAVEN					
23	46	24	8	7	5	4	1	5	.088-.0625	.-	3.0	cb
	46	70	78	85	90	94	95	100				
24	45	19	6	8	4	3	4	10	.0625-.044	.20	5.2	a
	45	64	70	78	82	85	89	99				
25	62	16	6	6	4	3	1	2	.177-.125	.03	3.5	cb
	62	78	84	90	94	97	98	100				
26	55	22	7	7	3	2	2	3	.177-.125	.05	5.5	a
	55	77	84	91	94	96	98	101				
27	46	20	8	7	5	4	2	9	.0625-.044	.08	3.0	a
	46	66	74	81	86	89	91	100				
28	49	19	7	8	4	3	3	7	.088-.0625	.28	5.5	a
	49	68	75	83	87	90	93	100				
29	31	25	11	10	7	5	2	10	.0625-.044	.30	3.5	cb
	31	56	67	77	84	89	91	101				
30	55	17	6	6	3	2	3	8	.0625-.044	.10	3.5	cb
	55	72	78	84	89	92	100					
31	57	17	6	5	4	3	2	7	.088-.0625	.08	4.0	cb
	57	74	80	85	89	92	94	101				
32	38	22	9	11	4	3	4	8	.0625-.044	.59	7.0	cb
	38	60	69	80	84	87	91	99				

FIGURE 4. X-ray diffraction pattern of oriented clay mount typical of mountain soils containing non-expansive clays.

Q, quartz; M, mica; Ch, chlorite; F, feldspar; K, kaolinite.


Q,M
51% RELATIVE HUMIDITY
GLYCOLATION EFFECT
HEATING EFFECT 300°C.
HEATING EFFECT 550°C.
F
M
Q
M
F
K
DEGREES 2 θ (THETA)
SAMPLE 14
28 26 24 22 20 18 16 14 12 10 8 6 4

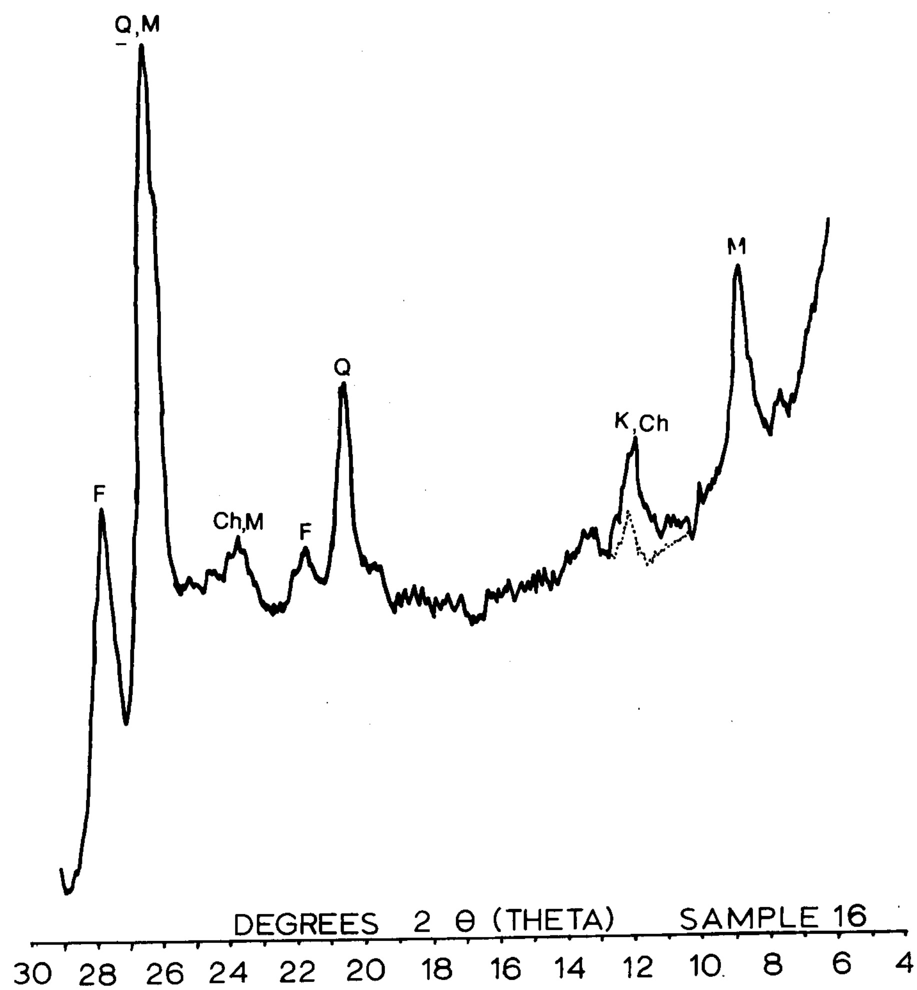
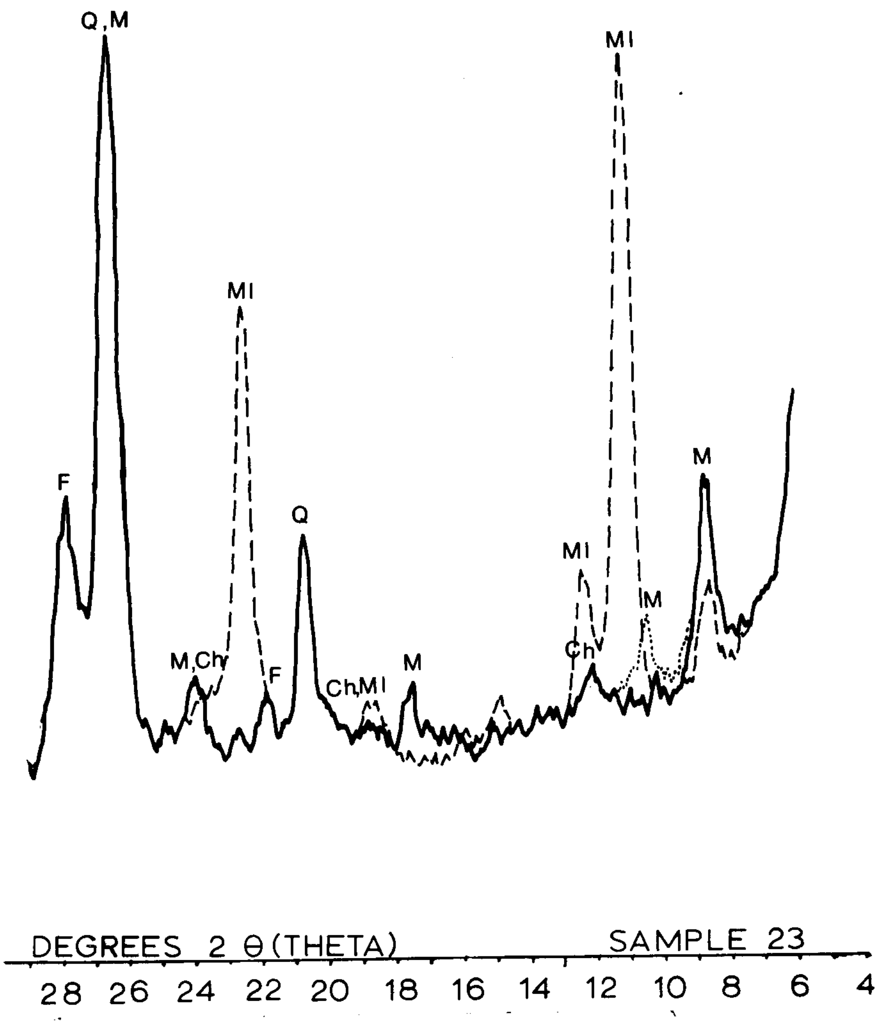

Q,M
M
Q
K,Ch
F
Ch,M
F
DEGREES 2 θ (THETA)
SAMPLE 16
30 28 26 24 22 20 18 16 14 12 10 8 6 4

FIGURE 5. X-ray diffraction pattern of oriented clay mount typical of mountain soils containing expansive clays.

Q, quartz; M, mica; Ch, chlorite; F, feldspar; K, kaolinite; Ml, mixed-layered minerals containing montmorillonite.


Q,M
MI
MI
F
Q
M
MI
M
M,Ch
F
Ch,MI
M
Ch
DEGREES 2 Θ(THETA)
SAMPLE 23
28 26 24 22 20 18 16 14 12 10 8 6 4

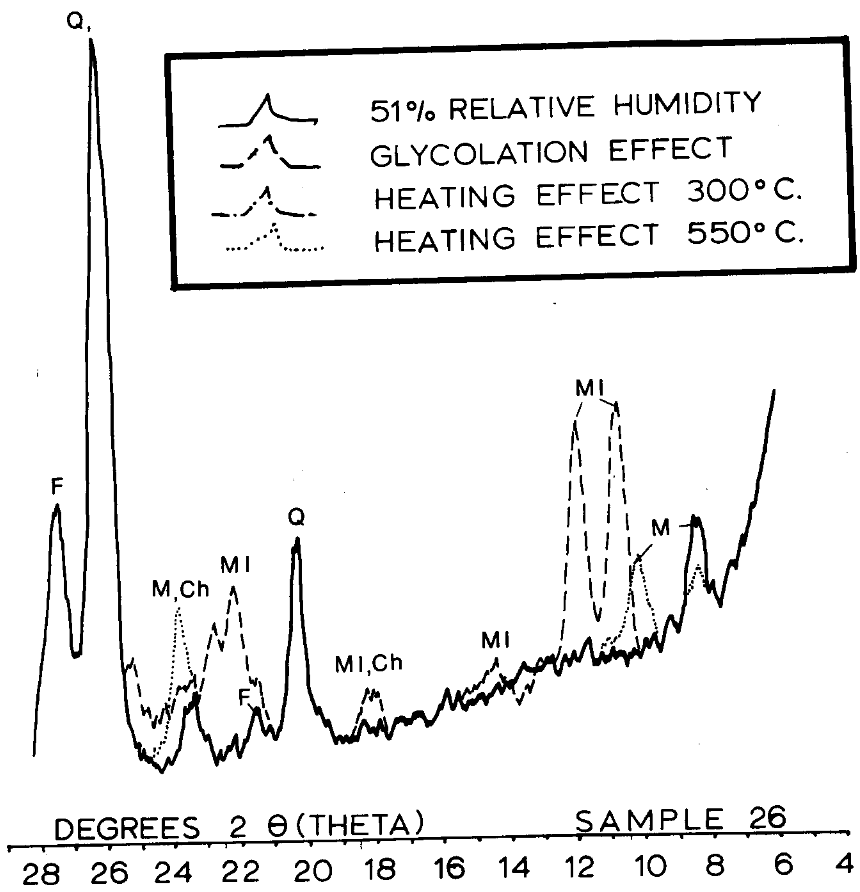
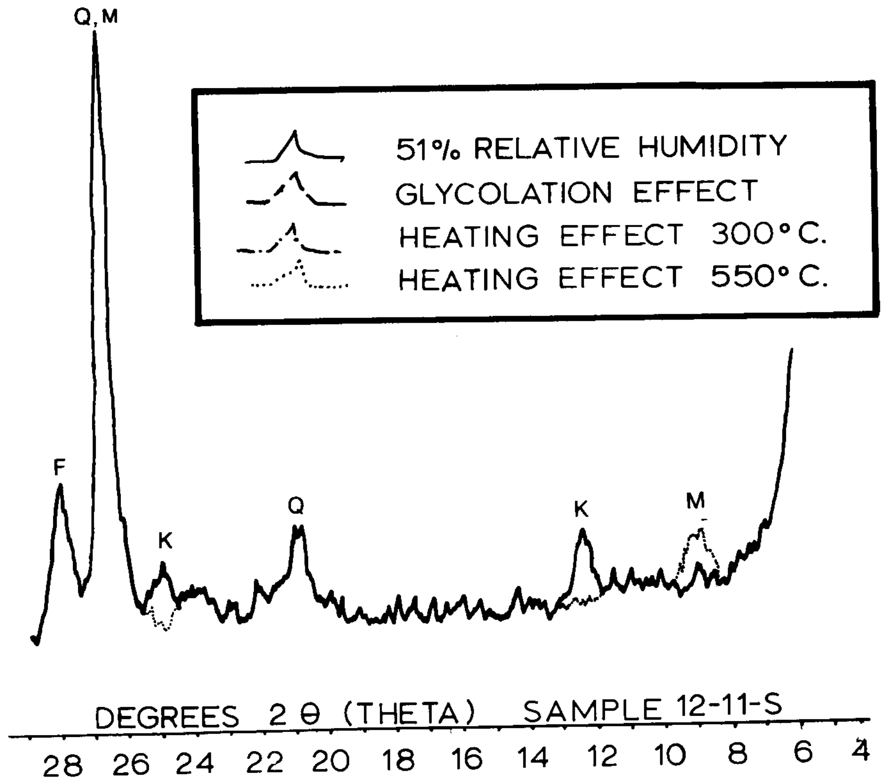

Q,
51% RELATIVE HUMIDITY
GLYCOLATION EFFECT
HEATING EFFECT 300° C.
HEATING EFFECT 550° C.
MI
F
Q
M
M,Ch
MI
F
MI,Ch
MI
DEGREES 2 Θ(THETA)
SAMPLE 26
28 26 24 22 20 18 16 14 12 10 8 6 4

FIGURE 6. X-ray diffraction pattern of oriented clay mount typical mountain soil containing an expansive clay (27) and rock weathering product containing non-expansive clay (12-11-S).

Q, quartz; M, mica; Ch, chlorite; F, feldspar; K, kaolinite; Ml, mixed-layered minerals containing montmorillonite.


Q,M
51% RELATIVE HUMIDITY
GLYCOLATION EFFECT
HEATING EFFECT 300° C.
HEATING EFFECT 550° C.
F
K
Q
K
M
DEGREES 2 θ (THETA) SAMPLE 12-11-S
28 26 24 22 20 18 16 14 12 10 8 6 4

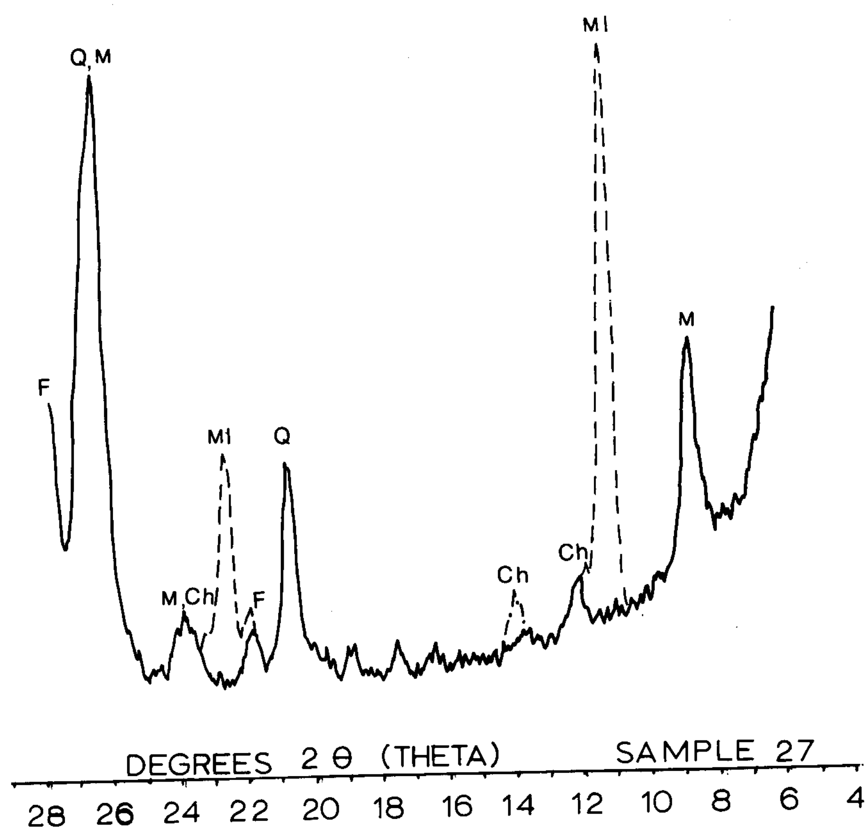

Q,M
Ml
M
F
Ml
Q
M Ch
F
Ch
Ch
DEGREES 2 θ (THETA) SAMPLE 27
28 26 24 22 20 18 16 14 12 10 8 6 4

TABLE 3. X-ray diffraction analysis of clay minerals present in mountain soils and as rock weathering products. Table lists dominant clay types only and the corresponding diffraction pattern which is presented in Figure 12 thru 14 that represents each clay analyzed.

Sample Number	Clay	Representative Pattern
	TALL TIMBERS	
1	Kaolinite	14
2	Kaolinite	14
3	Kaolinite	14
4	Kaolinite	14
5	Kaolinite	14
6	Kaolinite, Chlorite	16
7	Kaolinite	14
8	Kaolinite	14
9	Kaolinite	14
10	Kaolinite	14
11	Kaolinite, Chlorite	16
12	Kaolinite, Chlorite	16
13	Kaolinite	14
14	Kaolinite	14
12-10-S	Mixed-layer (montmorillonite-chlorite)	23
12-11-S	Kaolinite	12-11-S
	CRESCENT PARK	
15	Kaolinite	14
16	Kaolinite, Chlorite	16
17	Kaolinite	14
18	Kaolinite	14
19	Kaolinite	14
20	Mixed-layer (montmorillonite-chlorite)	23

TABLE 3. (continued)

Sample Number	Clay	Representative Pattern
21	Kaolinite	14
22	Kaolinite, Chlorite	
	GLEN HAVEN	
23	Mixed-layer (montmorillonite-chlorite)	23
24	Kaolinite, Chlorite	16
25	Kaolinite, Chlorite	16
26	Mixed-layer (montmorillonite-chlorite)	26
27	Mixed-layer (montmorillonite-chlorite)	27
28	Mixed-layer (montmorillonite-chlorite)	27
29	Kaolinite	14
30	Kaolinite	14
31	Mixed-layer (montmorillonite-chlorite)	27
32	Kaolinite	14

Data from each area were summarized as to the suitability of the soils for leach field systems and listed in the soil section of the summary for each area. Included in the soil summary is the data on percolation rates as obtained from county health department records, sieve analysis and soil depth. Clay mineralogy did not vary a great deal within the individual study areas and accounted for less than 1 percent of the soil, thus, was not used in the evaluation.

Physical Setting

In addition to the controls placed on the ground water system by local geology, there are also many purely physical controls on ground water movement which may be just as important and were taken into account. For example, the direction and steepness of slopes, the regional slope of the land, and age and density of homes all must be considered when trying to determine the amount and direction of movement of pollution. Thus for each area studied the following physical parameters were also considered and where possible measurements were obtained:

1) age of development,

2) type of sewage disposal systems,

3) percent of slope, and

4) regional slope of the land.

Slope maps were made for the Crescent Park and Tall Timbers areas (Plates 2 and 10). The slope maps were made by digitizing elevation data from enlarged U.S. Geological Survey topographic maps. The digitizing was done at the Engineering Research Center of Colorado State University on an Auto-Trol semi-automatic digitizer. Data points were taken such that the average elevation and slope could be computed for each 100 ft. x 100 ft. cell area on the enlarged topographic map. The digitized data were used to generate computer-drawn topographic and slope maps using programs devised by Mr. R. S. Parker and Mr. W. W. Burt of Colorado State University. The programs operate by computing the average slope in percent of each 100 ft. x 100 ft. square cell on the topographic map and contouring these slope values at the same scale as the original topographic map. Computer-generated topographic maps were also made in order to compare with the original topographic data from the U.S. Geological Survey maps. This was done to check the accuracy of the digitizing and the computer programs only, and the computer-drawn topographic maps are not reproduced in this report. The computer-drawn slope maps of Crescent Park and Tall Timbers are presented as Plates 2 and 10, respectively. Areas with slopes greater than 30 percent are cross hatched on these maps; these areas are considered unsuitable for installation of septic tank-leach field type waste disposal systems. Slopes between 20 and 30 percent are not indicated as hazardous because the occurrence of polluted wells in areas with slopes between 20 and 30 percent was not significantly greater than the occurrence of polluted wells in areas with slopes less than 20 percent. It must be emphasized that this conclusion is based entirely on the data contained in this report and that other studies have indicated that slopes of 20-30 percent are hazardous for the installation of septic tank-leach field type systems (Franks, 1972a). It may be necessary to consider 20-30 percent slopes as hazardous in the future; however, more data are needed for this to be clearly shown.

Crescent Park

Crescent Park subdivision covers about one half of section 4 and is situated over hill crests, side slopes, and valley bottoms. Because the area drains into several small intermittent creeks, the topographic controls on ground water movement are very localized, that is, the ground water will tend to drain downward to the nearest creek. There are no perennial streams in the subdivision. However, there are two springs, these yield small amounts of water which goes underground after a short distance. In general, the area is well drained and most of the precipitation enters the ground water system through fractures in the bedrock. The slope map for the area is given on Plate 2. Slopes are in percent.

The ground water configuration generally reflects the topography, being shallow in the valley bottoms and deep under the ridges.

The regional flow of the ground water is in the direction of Coal Creek. The amount of water available for individual homes appears to be sufficient and at least one well in the subdivision produces enough water to be used as a municipal supply (35 gpm) should the need arise (see Appendix 2, Table 1, lot 67).

Tall Timbers

The Tall Timbers subdivision covers approximately one-fourth of section 33 and is located almost entirely on steep side slopes. The slope map for the area is given on Plate 10. The topographic controls on shallow ground water movement is fairly consistent as almost the entire subdivision drains to the east into Bummers Gulch. A small intermittent creek runs through Bummers Gulch and will affect the quality of water in shallow wells producing from the alluvium. Its effect will be from induced recharge from the creek during the periods when it is not dry. This will affect only a few homes located near the creek and will generally be confined to high runoff periods after large storms.

The topography reflects the ground water configuration very well, with the water table being shallow toward the valley bottoms and becoming deeper higher up on the hill. The amount of water available for individual home use is sufficient, but no wells in the area produce enough water to be considered for municipal use.

Glen Haven

Glen Haven is an older mountain community and is used mainly as a summer resort area. For this reason the population varies considerably over the year. There are probably less than 50 year round residents while the resident population in the summer months may be as high as 200. In addition to this there are a large number of horses in the area during the summer months. These are used at the local youth camps and riding stables on trails.

Most of the wells in the area are shallow dug located near the streams in the alluvium. These wells rely on a high rate of infiltration from the streams for their water. Thus the quality of the surface water is reflected in the quality of the well water. This interaction between the surface water and the shallow ground water is clearly indicated by the tests for total dissolved solids. The results are of the same magnitude for surface water and shallow well water near the streams, while the deep drilled wells located away from the streams on hill sides and ridges are much higher in total dissolved solids (see Appendix 1, Tables 3 and 4).

The ground water configuration could only be determined near the streams as the data were not available over the entire area. There are several deep drilled wells in the area. However, these are located relatively near the streams also. Development has been limited to near the streams due to the steepness of the area.

Regional Climate

The Front Range is characterized by a temperate, relatively dry climate. The average annual temperature is between 40° F and 50° F. Maximum summer temperatures are generally below 100° F and minimum winter temperatures fall below freezing, sometimes to -30° F. More typical temperatures, however, are about 60° F for the summer and 30° F in the winter (see Table 1).

Mountain weather stations show a greater variation among themselves than do stations on the plains or foothills. This variety is due for the most part to the changes in topography over short distances. Climatological data compiled by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce for the 6 months ending 1972 are summarized in Table 4. This includes the entire period during which the water quality of each area was established. Data from Estes Park were used for the Glen Haven area and an average of the data for Boulder and a weather station two miles north-northeast of Nederland were used to describe both the Tall Timbers area and Crescent Park. These data indicate that the Glen Haven area received approximately 7.2 inches of precipitation with an average temperature of 46°. Tall Timbers and Crescent Park received about 10.1 inches of precipitation with an average temperature of 47° for the research period.

TABLE 4. Climatological data obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Data for period July to December, 1972, during water quality testing period.

STATION INDEX - all stations Platte River Drainage

Name	No.	County	Lat.	Long.	Elevation	Years of Record Temp.	Years of Record Prec.	Years of Record Evap.
Estes Park	2759	Larimer	40-23	105-31	7525	53	62	22
Boulder	0842	Boulder	40-00	105-16	5420	72	79	
Nederland 2 NNE	5878	Boulder	39-59	105-30	8240			

AVERAGE TEMPERATURE AND DEPARTURE FROM NORMAL

Name	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Last 6 Mo.
Estes Park	61.2	59.1	54.3	45.1	28.7	24.9	43.5	45.5
	-1.0	-1.8	.2	-.2	-5.8	-4.9	.5	
Boulder	69.9	69.0	62.0	51.6	34.0	27.9	50.8	52.4
	-3.7	-3.1	-2.3	-2.1	-7.4	-7.9	-1.0	
Nederland	57.2	55.9	49.6	40.9	23.9	21.0	39.3	41.4

TABLE 4. (continued)

TOTAL PRECIPITATION AND DEPARTURE FROM NORMAL

Name	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Last 6 Mo.
Estes Park	.49	2.61	1.39	1.32	.65	.71	11.70	7.17
	-1.64	.75	.15	.32	-.17	.06	-4.37	
Boulder	2.24	1.79	1.18	1.26	2.15	1.14	18.43	9.76
	.83	.15	-.07	-.13	1.19	.52	-.14	
Nederland	1.16	2.44	1.99	1.21	3.06	.67	17.27	10.53

TEMPERATURE EXTREMES AND FREEZE DATA

					First Fall Minimum				
Name	Highest	Date	Lowest	Date	32^{o}	28^{o}	24^{o}	20^{o}	16^{o}
Estes Park	88	7-31	-30	1-4	9/21	10/7	10/23	10/30	10/13
					29	28	22	12	12
Boulder	96	7-30	-16	12-6	10/15	10/29	10/30	10/30	10/30
					32	25	15	15	15
Nederland	86	7-31	-29	1-4	7/5	9/21	10/11	10/23	10/24
					32	25	23	17	16

Regional Geology

Each of the areas studied is located in the Front Range which is the eastern most Range in the Southern Rocky Mountains. This range is approximately 30 to 60 miles wide and about 250 miles long. In Wyoming it is known as the Laramie Range. It consists mainly of Precambrian gneiss, schist, and granitic intrusive rocks (Lovering and Goddard, 1950). The Range is a complexly faulted anticlinal arch on which are superposed numerous cross-folds and faults which divide it into five major fault-bounded structural belts (Boos and Boos, 1957).

Precambrian intrusive rocks are widespread in the Front Range and include the Boulder Creek Granodiorite, Silver Plume Granite, and Pikes Peak Granite. These occur as batholiths, plutons, and dikes which are locally porphyritic. The gneiss and schist occur as biotitic, feldspathic, and hornblendic units which were previously mapped as the Idaho Springs and Swandyke Formations (Lovering and Goddard, 1950). These rocks have been repeatedly deformed and now lie in a series of complex folds. In addition to these units, there are also many metalliferous deposits located in the central portion of the Front Range (Wells, 1967, Lovering and Goddard, 1950).

The entire Front Range is bordered by Paleozoic and Mesozoic sedimentary rocks that were upturned during the Laramide orogeny. Rotation of some of the Precambrian units and renewed displacement along the Precambrian fault system accompanied the orogeny (Wells, 1967). The Rogers and Hoosier "breccia reef" are part of the Precambrian fault system that was reactivated during the Laramide. The Tertiary rocks in the Front Range include conglomerate, sandstone, shale, and dikes of diabase and latite porphyry (Wells, 1967). Pleistocene and Recent deposits include glacial material in the high mountains, and alluvial and colluvial deposits which occur locally.

Local Geology

Each of the areas studied has been previously mapped on a large scale by the following workers: Wells (1967), "Geology of the Eldorado Springs Quadrangle"; Wrucke and Wilson, (1967), "Geology of the Boulder Quadrangle"; Gardner (1968), "Engineering Geology of the Eldorado Springs and Boulder Quadrangle"; and Bucknam (1969), "Structure and Petrology of part of the Glen Haven Quadrangle". The geology of the study areas for this investigation, which included the individual developments or subdivisions, was modified from that of previous workers on the basis of detailed field examination. The influence that the local geology has on the spreading of leach field effluent is summarized at the end of the geology section for each study area.

Crescent Park

Crescent Park is underlain by the Boulder Creek Granodiorite and a quartz monzonite (see Plate 1). The quartz monzomite is younger than the granodiorite and in the southern part of the Eldorado Springs Quadrangle has invaded the Boulder Creek Batholith. Inclusions of the batholithic rocks occur in various shapes and sizes in the quartz monzonite clearly indicating that the quartz monzonite is younger (Wells, 1967, p. 18). In Crescent Park the quartz monzonite occurs as a gray, fine to medium-grained rock with an average composition of 34 percent quartz, 29 percent microcline, 37 percent plagioclase, 3-7 percent biotite, 0-2 percent hornblende, and 0-1 percent muscovite. Accessory minerals make up less than 2 percent of the rock and include zircon, apatite, sphene, and opaque minerals. Foliations and lineations occur locally as alignment and streaking of biotite. The biotite is locally altered to chlorite and epidote is present in aggregated layers. When weathered the quartz monzonite appears pinkish and becomes iron stained when highly fractured. In intensely weathered outcrops it is highly friable and can be crumbled by hand. These areas are indicated on Plate 5 as weathered zones greater than 15 feet in depth.

The most abundant rock in the Crescent Park area is the Boulder Creek Granodiorite. Locally it occurs as a medium gray, faintly banded, medium to fine grained, locally porphyritic rock. The average composition is 28 percent quartz, 17 percent microcline, 44 percent plagioclase, 6-12 percent biotite, and 0-2 percent hornblende. Accessory minerals account for less than 2 percent of the rock and include apatite, zircon, sphene, and opaque minerals. Porphyritic varieties occur locally and some contain potassic feldspar phenocrysts up to an inch in length. Foliation is generally weak and occurs mainly as alignment of biotite crystals. In outcrop the Boulder Creek Granodiorite and the quartz monzonite weather in similar fashions. Because of this and the similar nature of the two rocks it is very difficult to establish a sharp contact between them.

Surficial deposits in Crescent Park include alluvial and colluvial deposits. The colluvium is of recent age and consists of locally derived solifluction debris overlying bedrock and surficial deposits. It occurs as a mixture of boulders, gravel, sand, silt, and clay that has accumulated at the base of steep slopes and may be as deep as 30 feet and support forest vegetation (Wells, 1967, p. 49). The areal extent and depth of colluvium in the Crescent Park area does not appear to be this great, and probably its thickness is less than 15 feet in all places. This could not be definitely confirmed but was indicated by the driller's logs for local water wells.

Alluvial deposits in the Crescent Park area are restricted to valley alluvium and consist of deposits in present stream channels. These deposits are equivalent to the pre-Piney Creek, Piney Creek, and post-Piney Creek of previous workers (Wells, 1967). All deposits in the study area are at or near stream level and consist of locally derived, well rounded, fairly well sorted, pebbles and cobbles that are one to four inches in diameter. These deposits are subject to reworking by flood waters and visual estimates indicate their maximum thickness is probably less than 15 feet in all areas of Crescent Park. There are no wells which produce from the alluvial deposits in Crescent Park.

Faults in the Crescent Park area include the Rogers fault zone which is a group of subparallel, branching, and cross faults that trend through the west part of the subdivision at approximately north 30° west. In Crescent Park this zone occurs as a broad, poorly cemented, and steeply dipping zone of fault breccia. This shear zone is evidenced by the subdued topography on the west side of Crescent Park subdivision and is shown in the road cut on Coal Creek Road just prior to entering the subdivision. This zone and one on the east side of the subdivision (see Plate 1) act as conduits to ground water flow. Because of the highly fractured nature of these zones the weathering is more intense and thus wells producing from these areas tend to have higher yields and more total dissolved solids as indicated by chemical tests (Appendix 1, Table 1). In addition to these zones, there are several other shorter faults which occur as fairly well cemented, narrow, breccia zones. These faults have a significant influence on ground water movement and act as barriers to ground water flow. Their influence does not seem to be as great as the shear zones.

Tall Timbers

Tall Timbers is underlain almost entirely on Boulder Creek Granodiorite. For the most part the granodiorite occurs as a coarse-grained quartzo-feldspathic biotite gneiss (see Plate 8). Foliation is due chiefly to parallel alignment of biotite crystals and to some extent to the parallel elongation of feldspar crystals. The average composition is 30 percent quartz, 20 percent microcline, 38 percent plagioclase, 0-17 percent biotite, and 0-32 percent hornblende. Accessory minerals account for less than 3 percent of the rock and include apatite, zircon, sphene, and opaque minerals. Locally, inclusions of biotite schist xenoliths are abundant showing very little evidence of assimilation. Associated with the xenoliths are some cataclastic seams filled with epidote. In outcrop the bedrock ranges from moderately to intensely weathered. This is evidenced by the rounded appearance of most outcrops, the many iron stained areas, and the friable nature of most bedrock samples. Drillers logs indicate this weathered zone extends to depths of from 10 to 50 feet (Table 2, Appendix 2). Plate 12 indicates the depths of intensive weathering by zones. Surficial deposits in the Tall Timbers area include the Piney Creek alluvium. These consist of valley alluvium deposits in present stream channels and terrace deposits above the stream bed.

FIGURE 7. Pole plot diagram of Crescent Park joints.

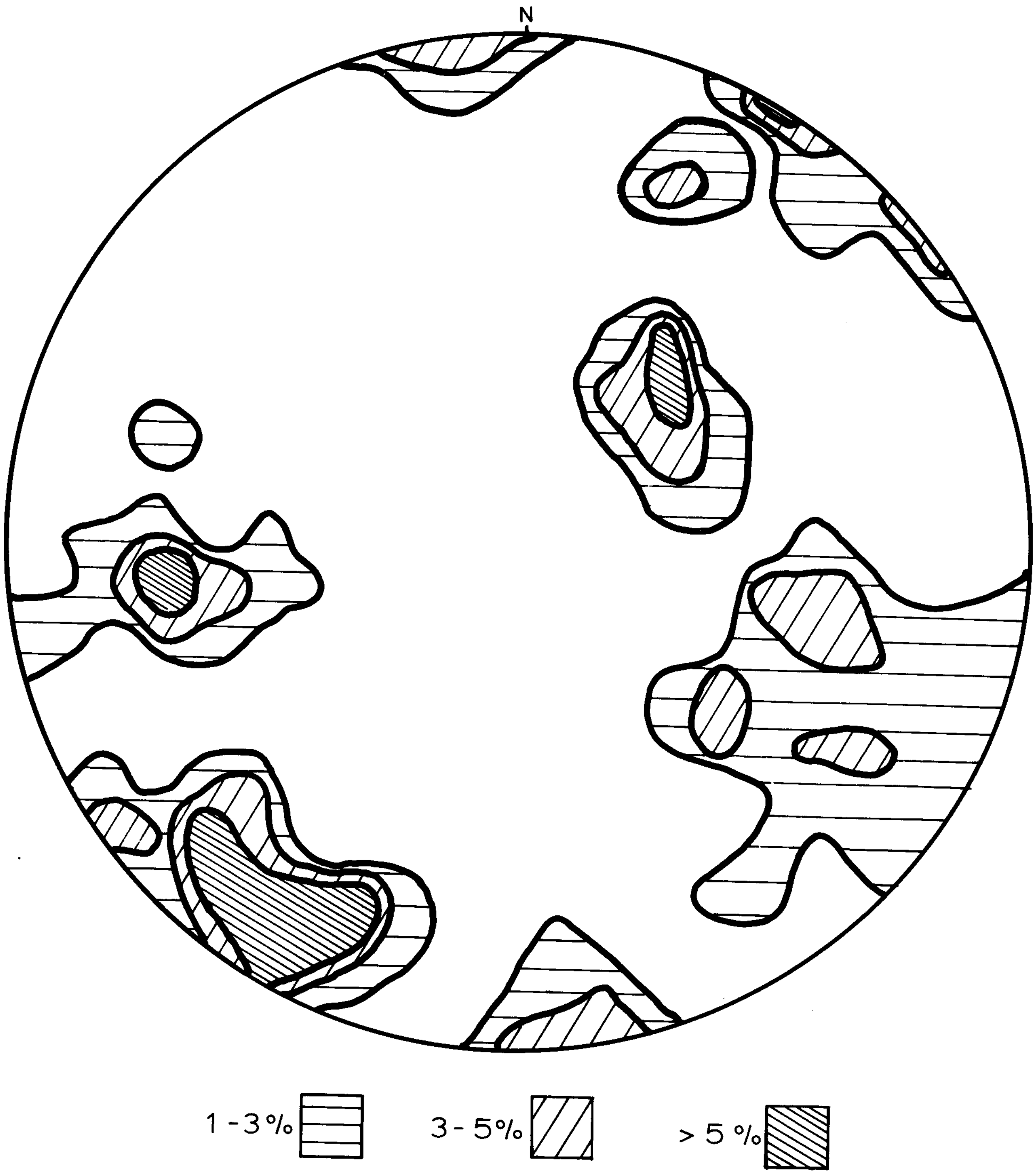
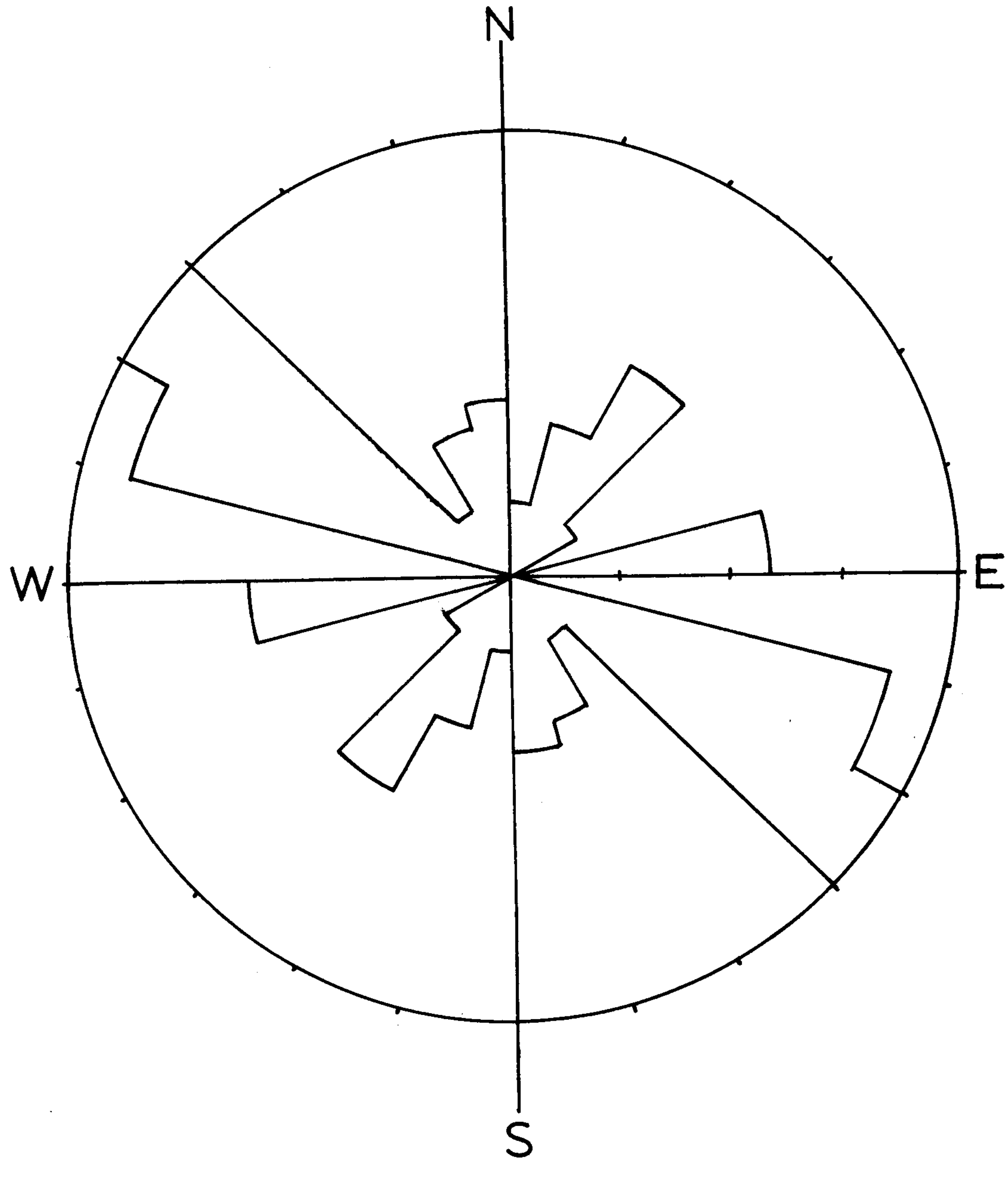

N
1-3%
3-5%
>5%

FIGURE 8. Rose diagram of Crescent Park joints.



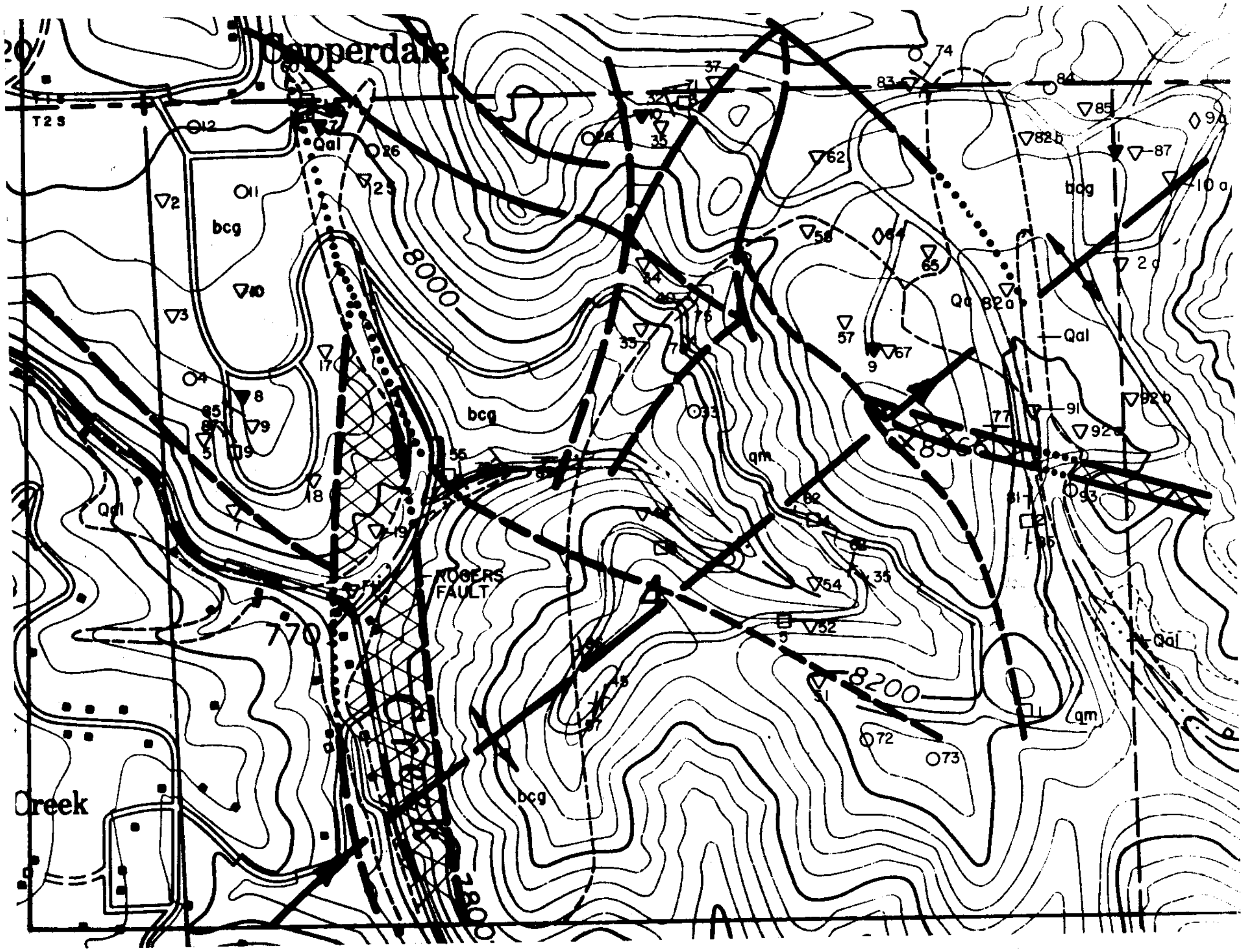
N
W
E
S

PLATE 1. Geologic map of Crescent Park.

GEOLOGIC MAP

Crescent Park

JEFFERSON COUNTY, COLORADO
T 2 S, R 71 W, Sec. 4
MODIFIED FROM J.D. WELLS
1965



EXPLANATION FOR GEOLOGIC MAP

SURFICIAL DEPOSITS

Quaternary
- Qal — Alluvium
- Qc — Colluvium

IGNEOUS ROCKS

Precambrian
- qm — Quartz monzonite
- bcg — Boulder Creek Granodiorite
- P — Pegmatite

- Fault, Shear Zone
- Vein
- Prospect Pit
- Anticline
- 30 Strike and Dip of Foliation
- 30 Strike and Dip of Joints
- 30 Bearing and Plunge of Lineation
- Contact– Dashed Where Approximately Located

- Well Locations
- Pollution Indicators
- Variable Pollution Indicators
- Safe Wells
- Soil Samples
- Bedrock Samples

SCALE

500 0 500 1000

GN MN 0°12' 13.5° 1966

Contour Interval 40 Feet
Datum Mean Sea Level

Burns
McCrumb
Morrison
1973

PLATE 2. Slope map - Crescent Park.

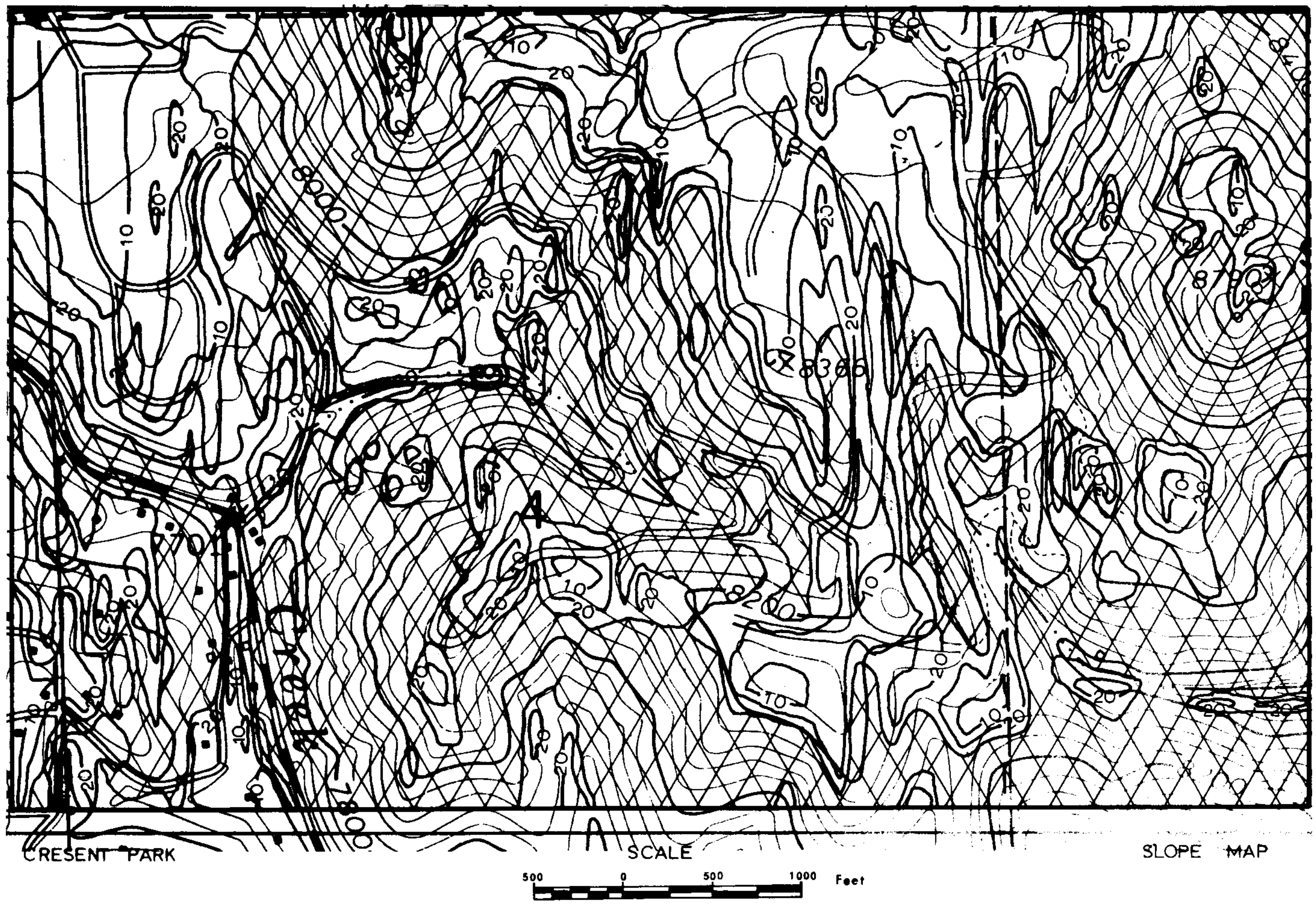

Creek
8000
CRESENT PARK
SCALE
500 0 500 1000 Feet
SLOPE MAP

PLATE 3. Soil thickness overlay for Crescent Park subdivision.

0 to 5 Feet - Unsuitable

5 to 10 Feet - Hazardous

10 or more Feet - Safe

SOIL THICKNESS
CRESENT PARK

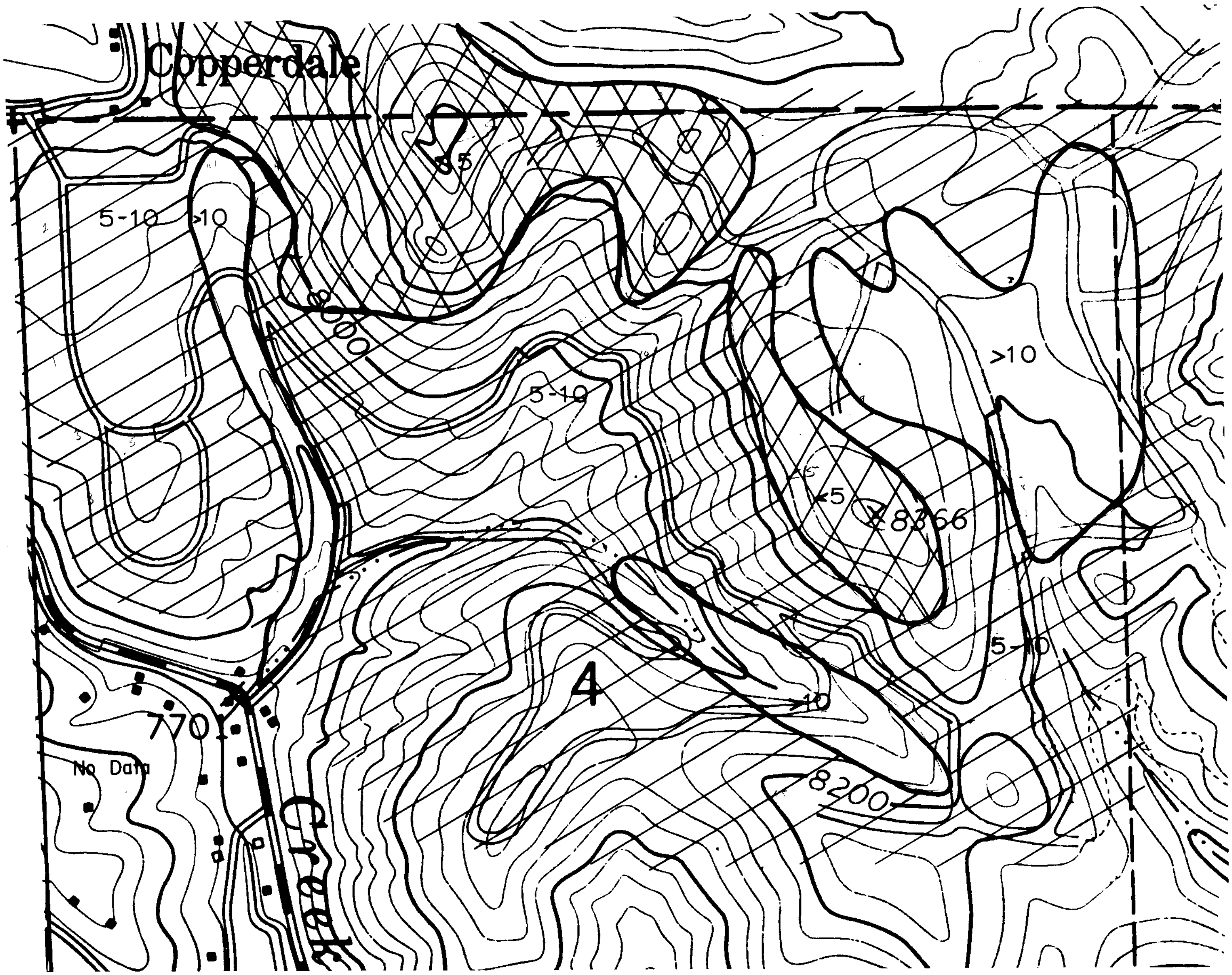


PLATE 4. Water table overlay for Crescent Park showing depth to the water table.

0 to 10	Feet - Unsuitable
10 to 15	Feet - Hazardous
15 or more	Feet - Safe

WATER TABLE DEPTH
CRESENT PARK

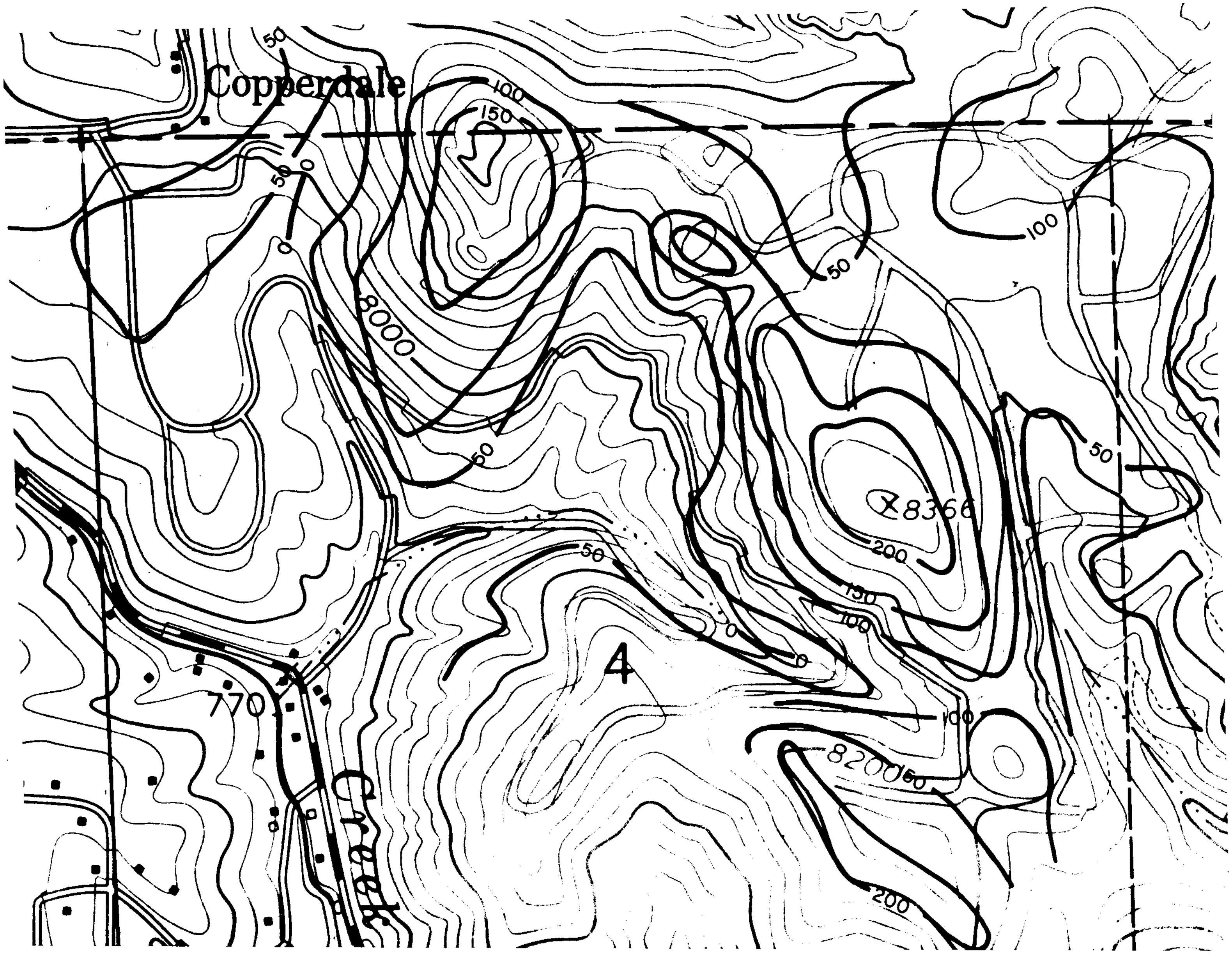


PLATE 5. Water table elevation overlay.

WATER TABLE ELEVATION
CRESENT PARK
CONTOUR INTERVAL 50 FEET

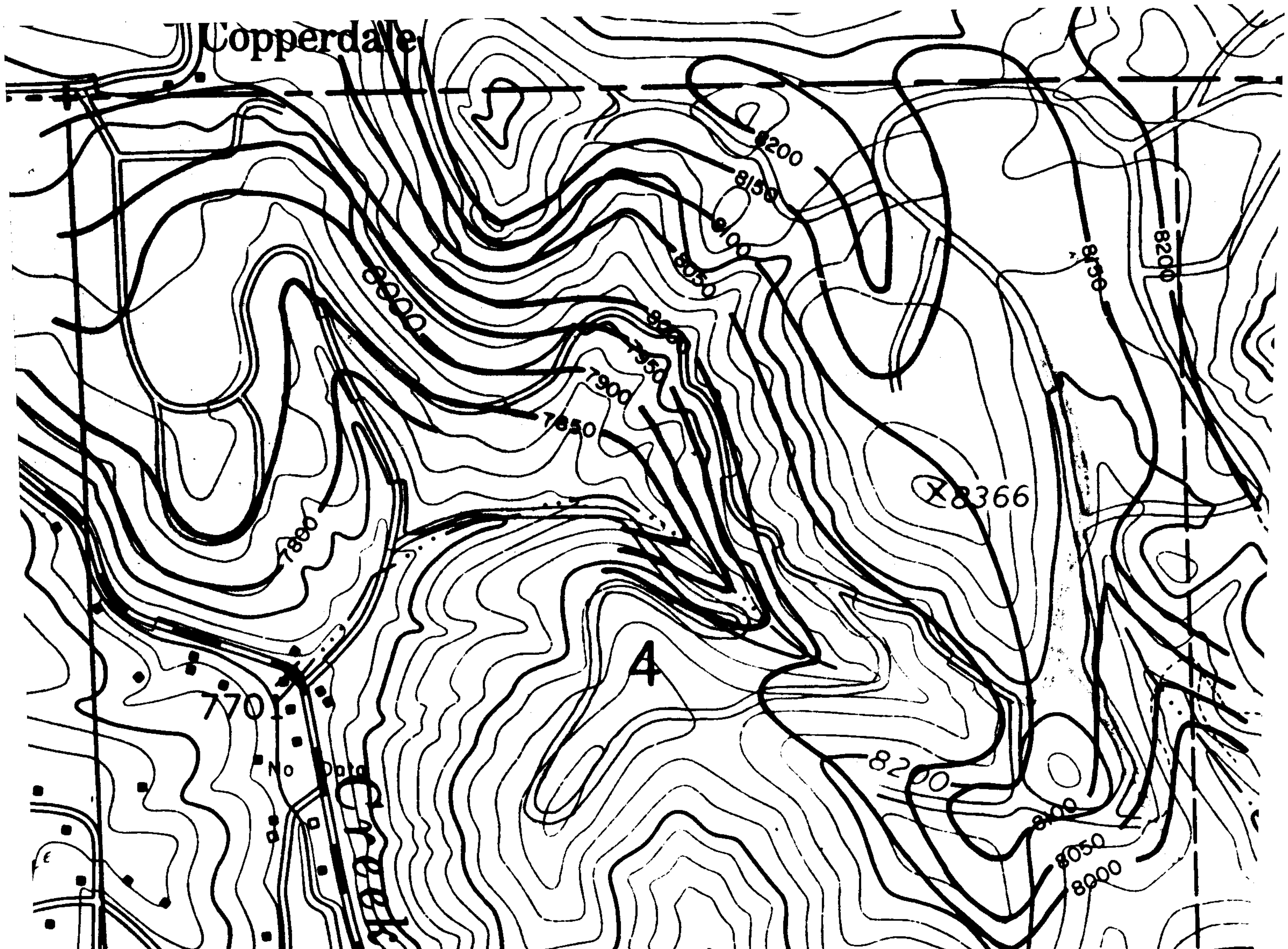


PLATE 6. Overlay indicating zones of intensely weathered bedrock for Crescent Park. Note - categories for the suitability of weathered bedrock for use as soil absorption systems have not been established.

0 to 5 Feet

5 to 15 Feet

15 or more Feet

WEATHERED BEDROCK THICKNESS
CRESENT PARK

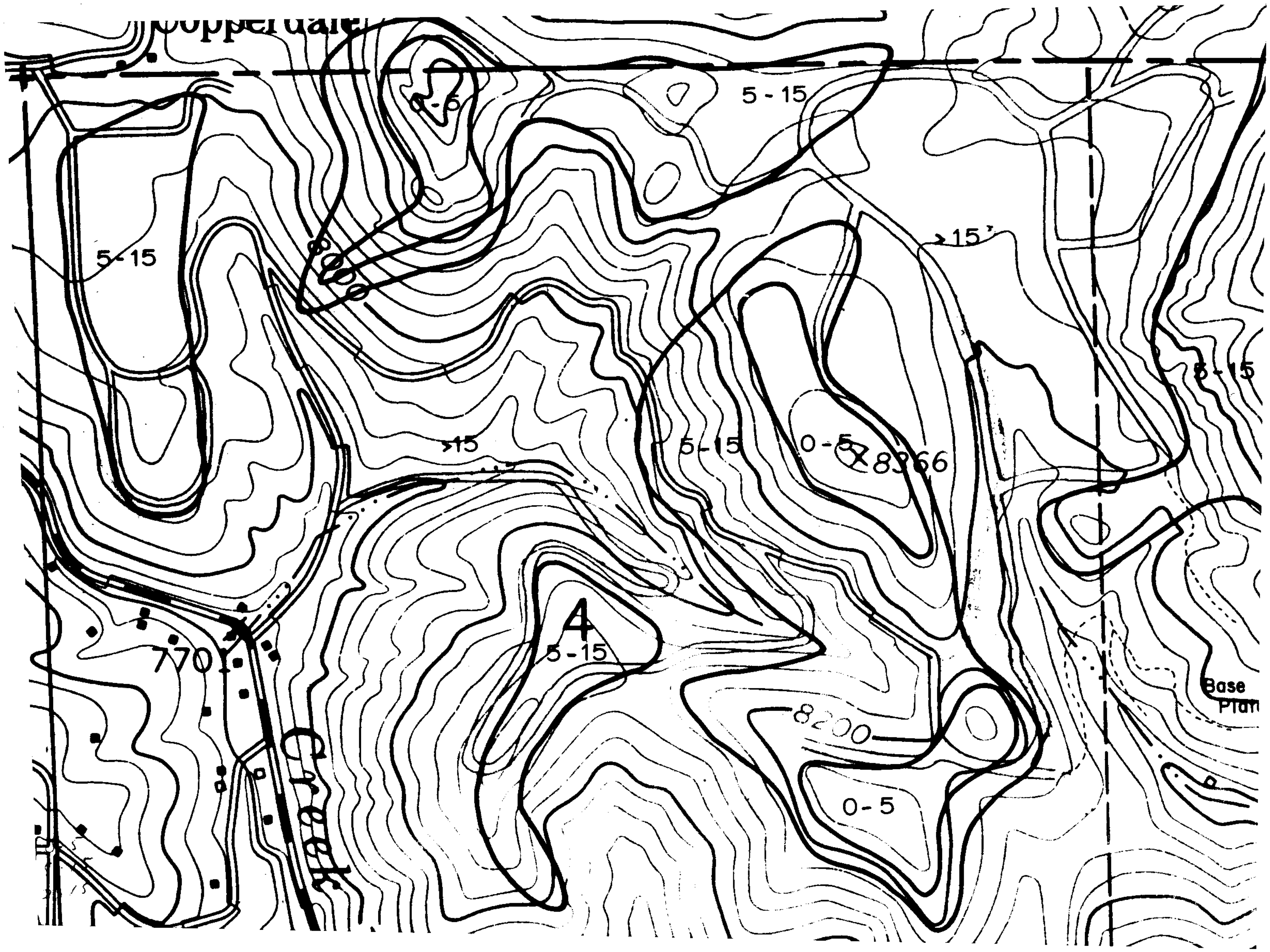


PLATE 7. Overlay indicating zones of different percolation rates for Crescent Park. Note - all percolation rates of less than 60 minutes per inch are acceptable to Jefferson County.

less than		10	Min. per inch - Hazardous
10	to	20	Min. per inch - Safe
20	to	60	Min. per inch - Safe
60 or more			Min. per inch - Unsuitable

PERCOLATION RATE
CRESENT PARK

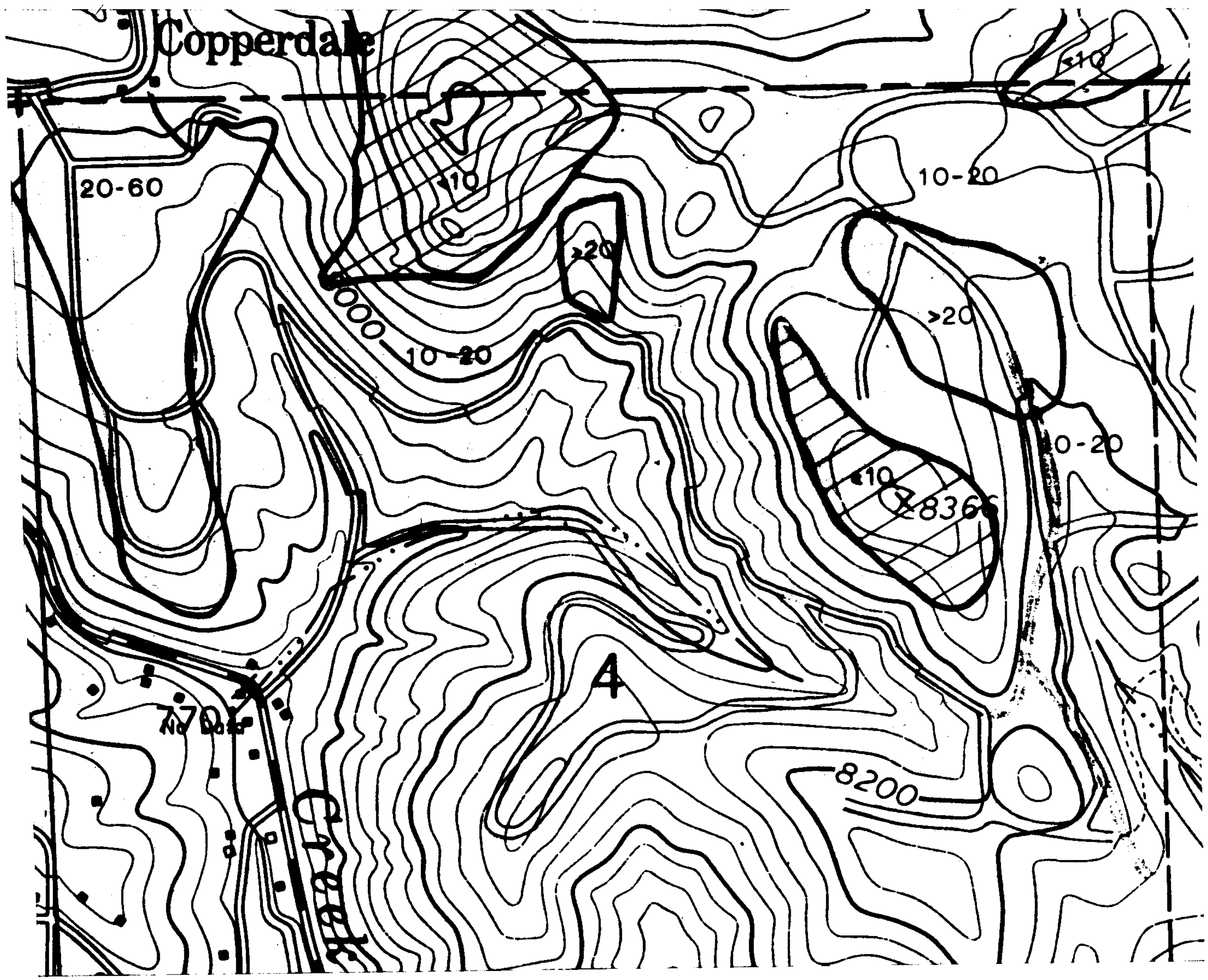


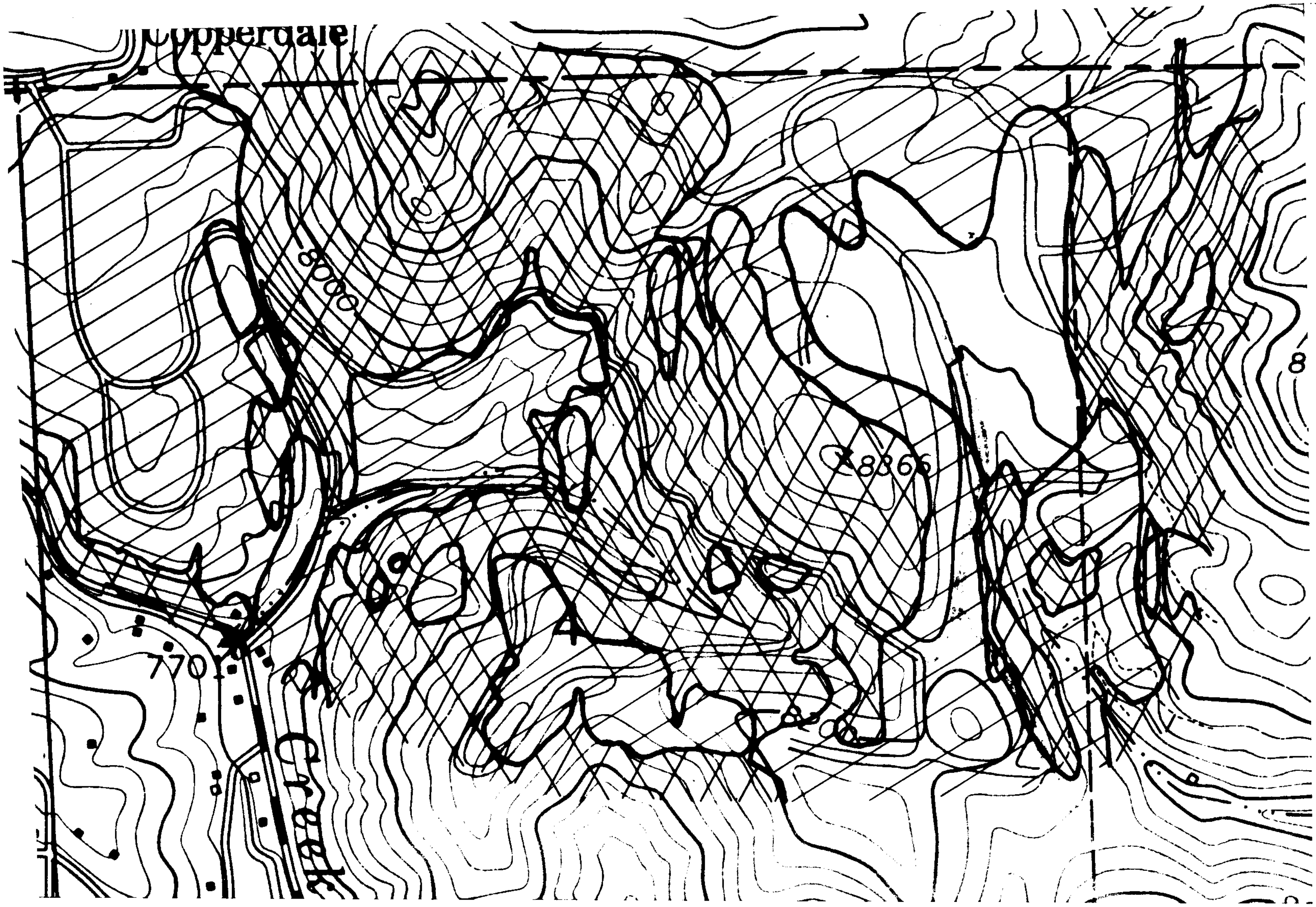
PLATE 8. Composite overlay showing hazardous and unsuitable areas for soil absorption systems in Crescent Park.

Unsuitable -

Hazardous -

Safe

COMPOSITE OVERLAY
CRESENT PARK



It occurs as a mixture of well rounded, fairly well sorted, pebbles and cobbles and a dark gray, humic, silty, coarse sand. Younger soils occur in the upper part of the Piney Creek which locally included alluvium of Wisconsin age that commonly underlies the Piney Creek Alluvium (Wrucke, 1967). In addition to the alluvium, there is colluvium covering part of the study area; however, it is generally very thin and thus was mapped only in areas where it was possible to distinguish it from the soil (see Plate 8).

The major joint spacing in Tall Timbers generally ranges from three to six feet. However, near the shear zones the bedrock is so friable and weathered as to appear granulated. In these areas there is a great deal of clay minerals present and the joint spacing may be only a matter of one to three inches. X-ray analysis of two samples of clay present as weathering products indicates that one sample is predominately Kaolinite and the other sample is expansive mixed layer clays. The trend of the joints and folations is north 45-60^{o} east in the major joint set and north 75-90^{o} east and north 30-45^{o} west for the two minor trends. Figure 9 is a diagram showing a pole plot of the joints and foliations and Figure 10 is a rose diagram of the strike directions.

The Hoosier fault or "breccia reef" trends about north 30^{o} west and divides the Tall Timbers subdivision in half (see Plate 9). It occurs as a zone of branching and subparallel fractures that

FIGURE 9. Pole plot diagram of Tall Timbers joints and foliations.

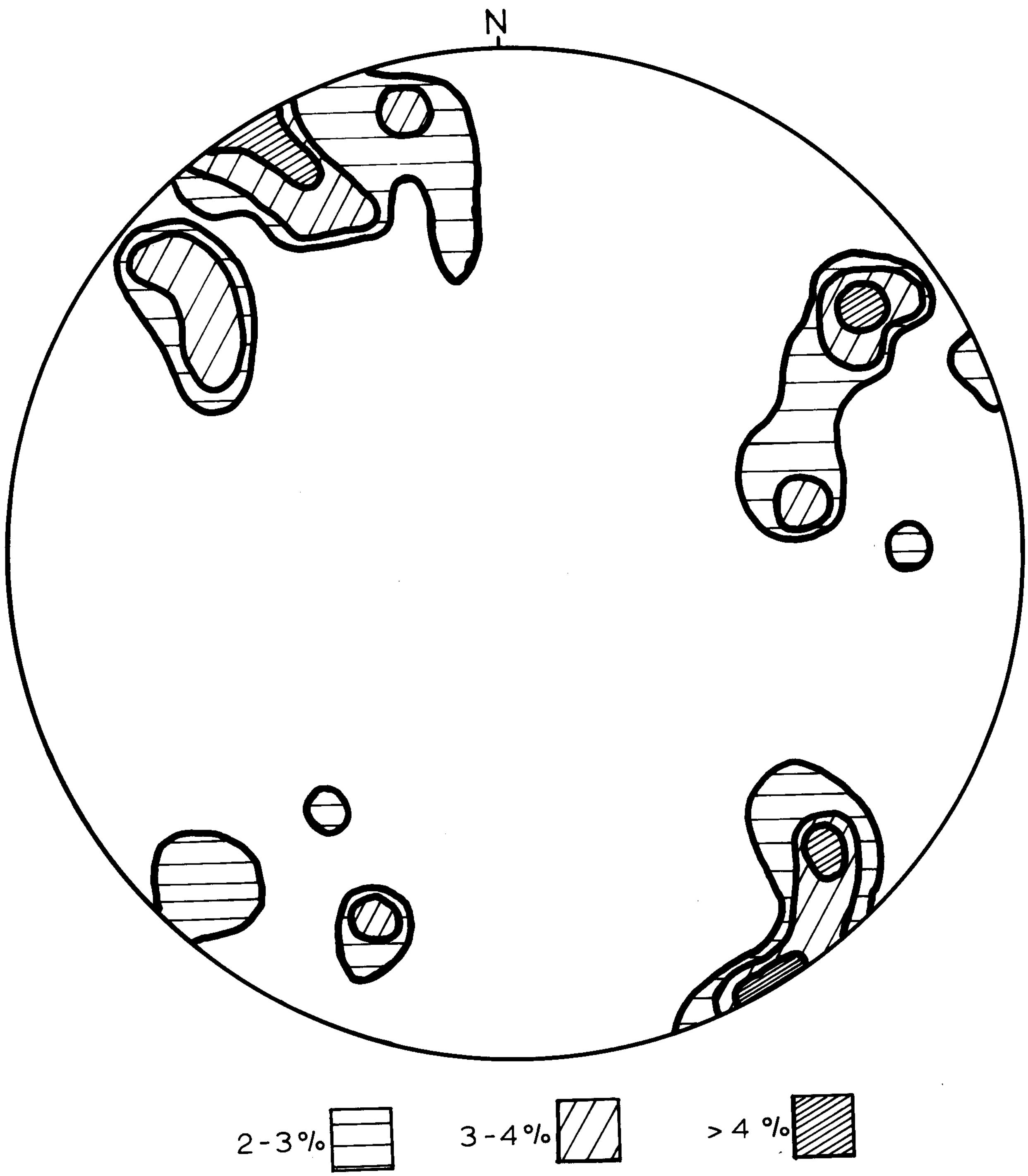

N
2-3%
3-4%
>4 %

FIGURE 10. Rose diagrams of Tall Timbers joints and foliations.

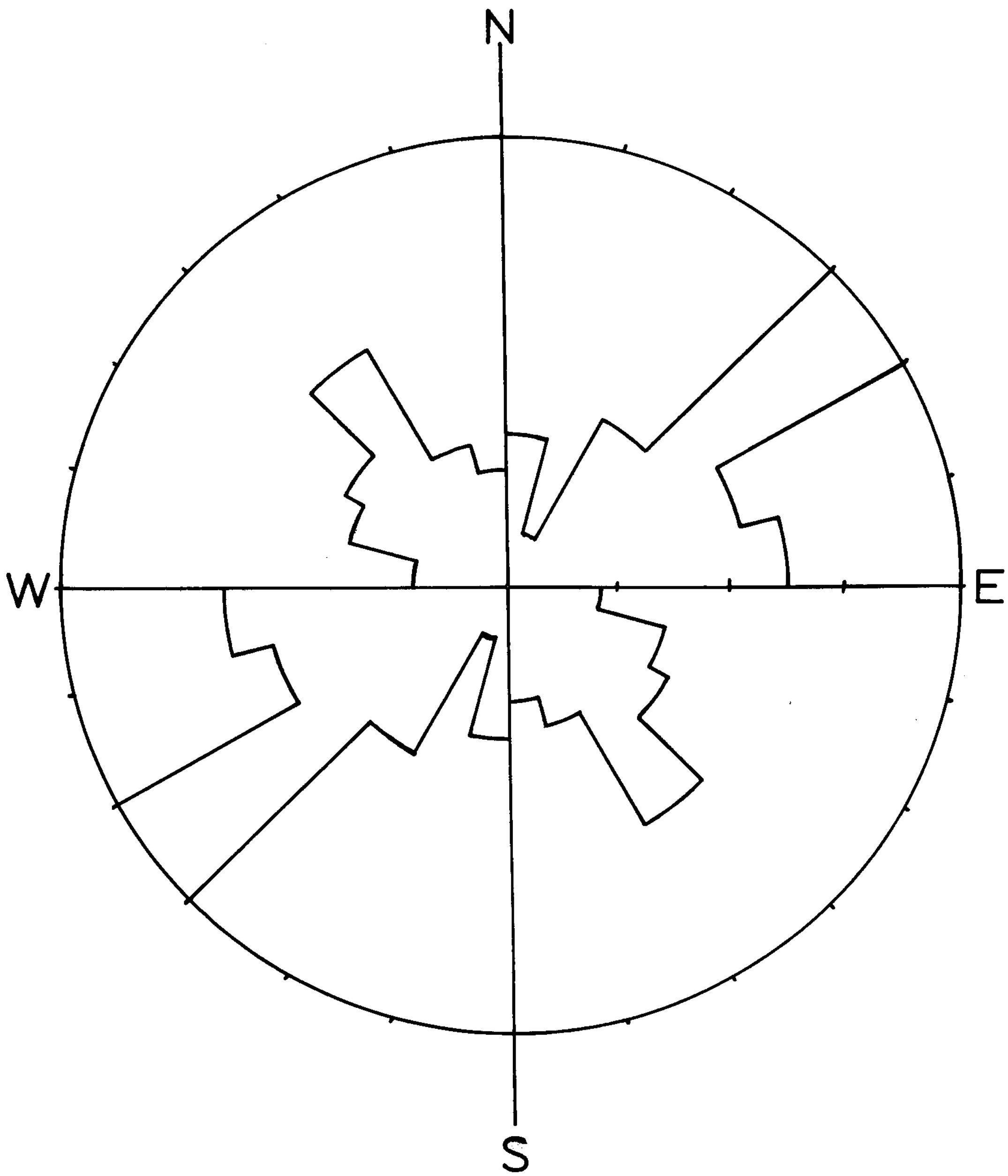

N
E
S
W

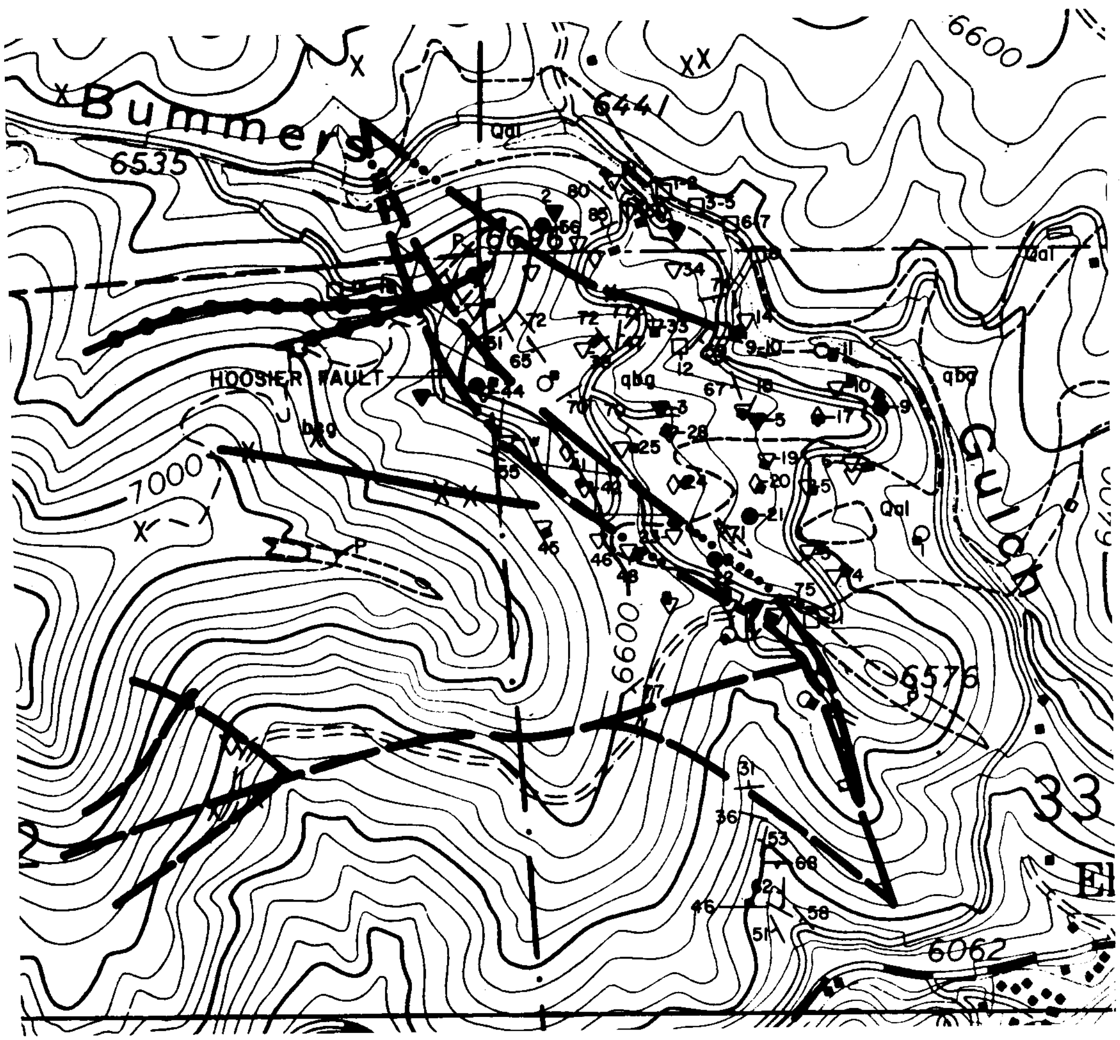
PLATE 9. Geologic map of Tall Timbers.

GEOLOGIC MAP

Tall Timbers

BOULDER COUNTY, COLORADO
T 1 N, R 71 W, Sec. 33

Modified from C.T. Wrucke & R. Wilson
1967



EXPLANATION FOR GEOLOGIC MAP

SURFICIAL DEPOSITS

Quaternary
- Qal — Alluvium
- Qc — Colluvium

IGNEOUS ROCKS

Precambrian
- bcg — Boulder Creek Granodiorite
- P — Pegmatite

METAMORPHIC ROCKS

- qbg — Quartzo-feldspathic biotite schist

- Fault, Shear Zone
- Vein
- Prospect Pit
- Anticline
- Strike and Dip of Foliation
- Strike and Dip of Joints
- Bearing and Plunge of Lineation
- Contact – Dashed Where Approximately Located

- Well Locations
- Pollution Indicators
- Variable Pollution Indicators
- Safe Wells
- Soil Samples
- Bedrock Samples

GN MN
0°12' 13.5°
1966

SCALE

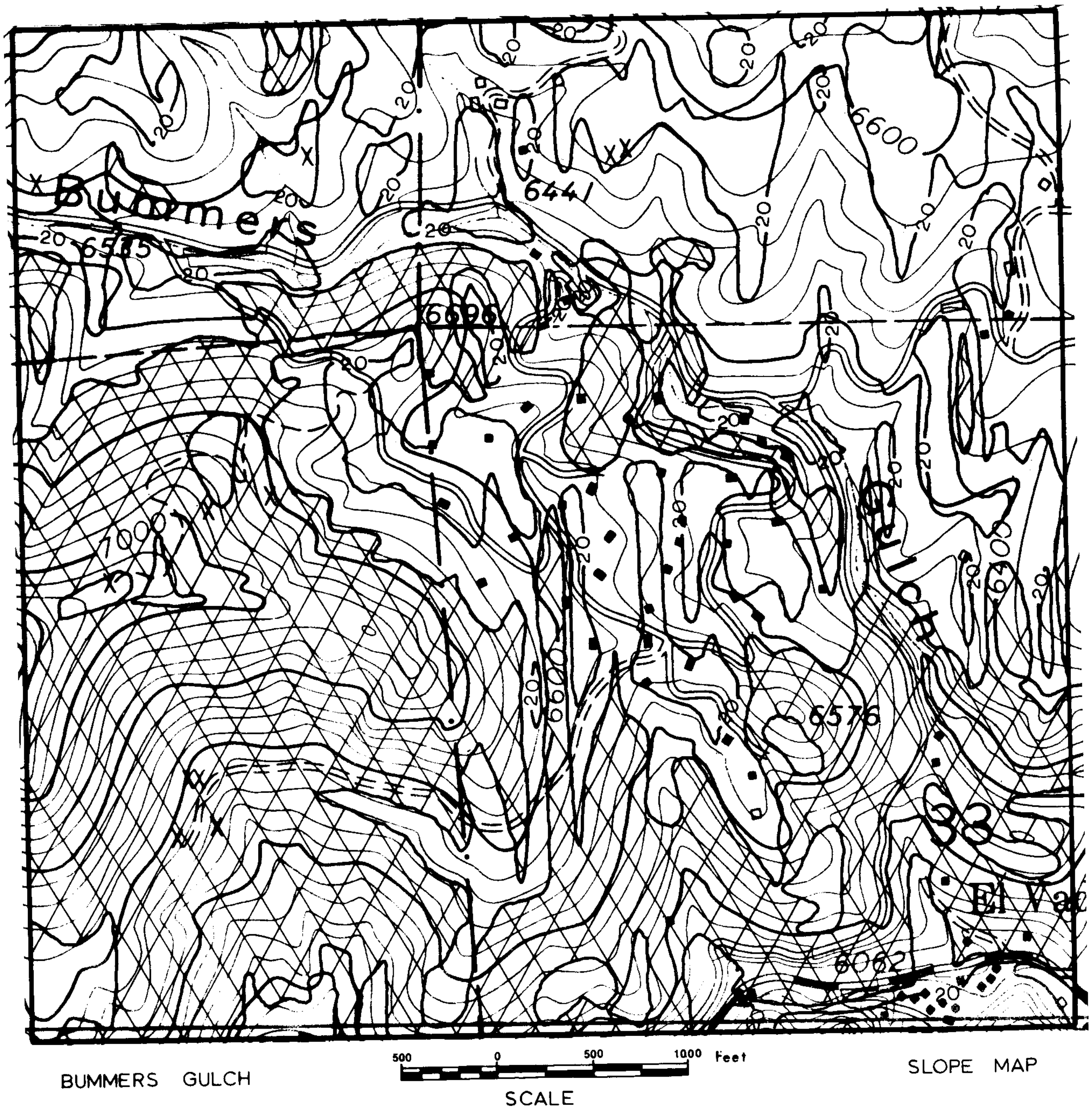
500 0 500 1000

Contour Interval 40 Feet

Datum Mean Sea Level

Burns
McCrumb
Morrison
1973

PLATE 10. Slope map - Tall Timbers.



BUMMERS GULCH

SLOPE MAP

PLATE 11. Soil thickness overlay for Tall Timbers subdivision.

0 to 5	Feet - Unsuitable
5 to 10	Feet - Hazardous
10 or more	Feet - Safe

SOIL THICKNESS
TALL TIMBER

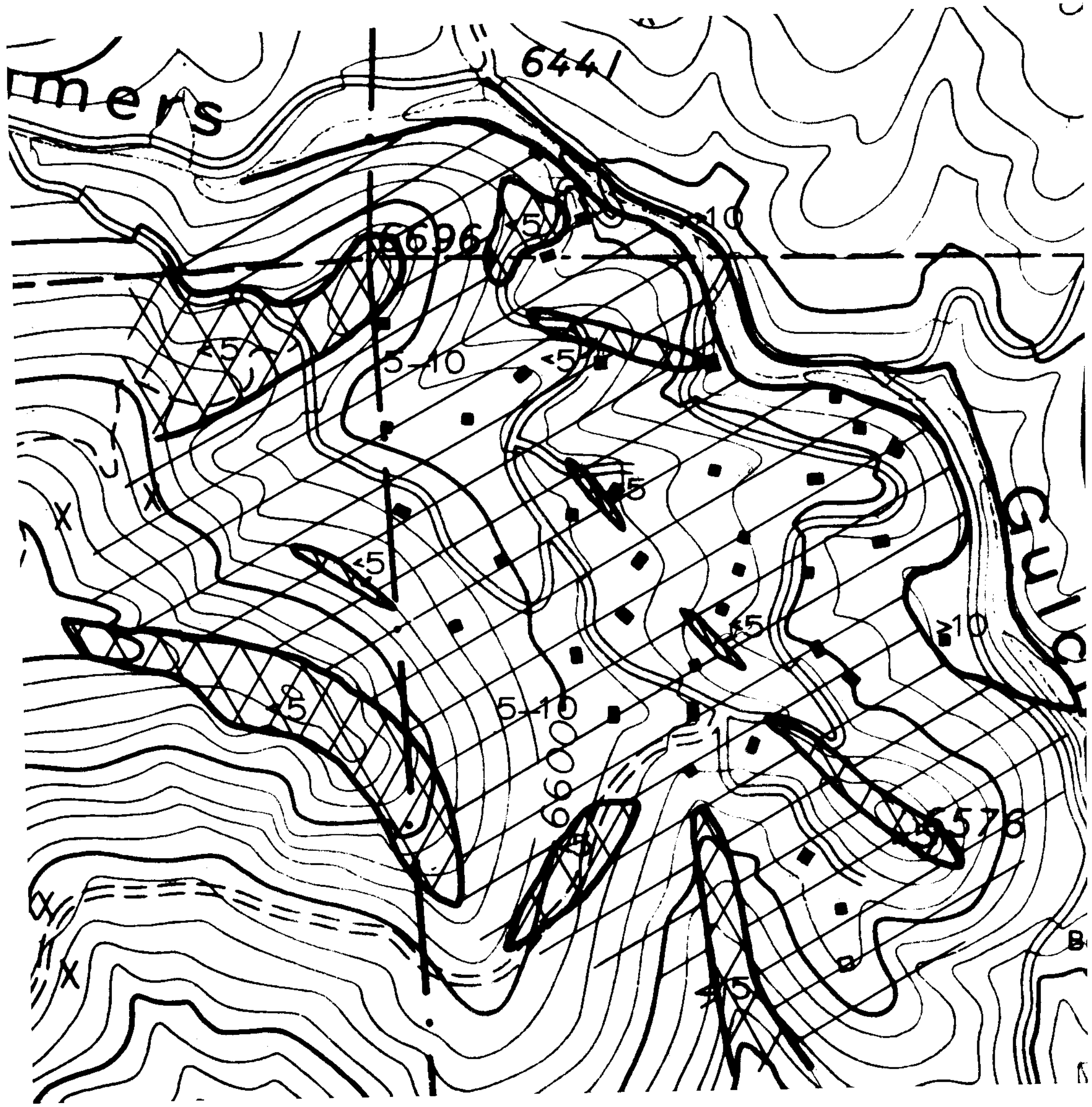


PLATE 12. Water table overlay for Tall Timbers showing depth to water table.

0 to 10	Feet - Unsuitable
10 to 15	Feet - Hazardous
15 or more	Feet - Safe

WATER TABLE DEPTH
TALL TIMBER

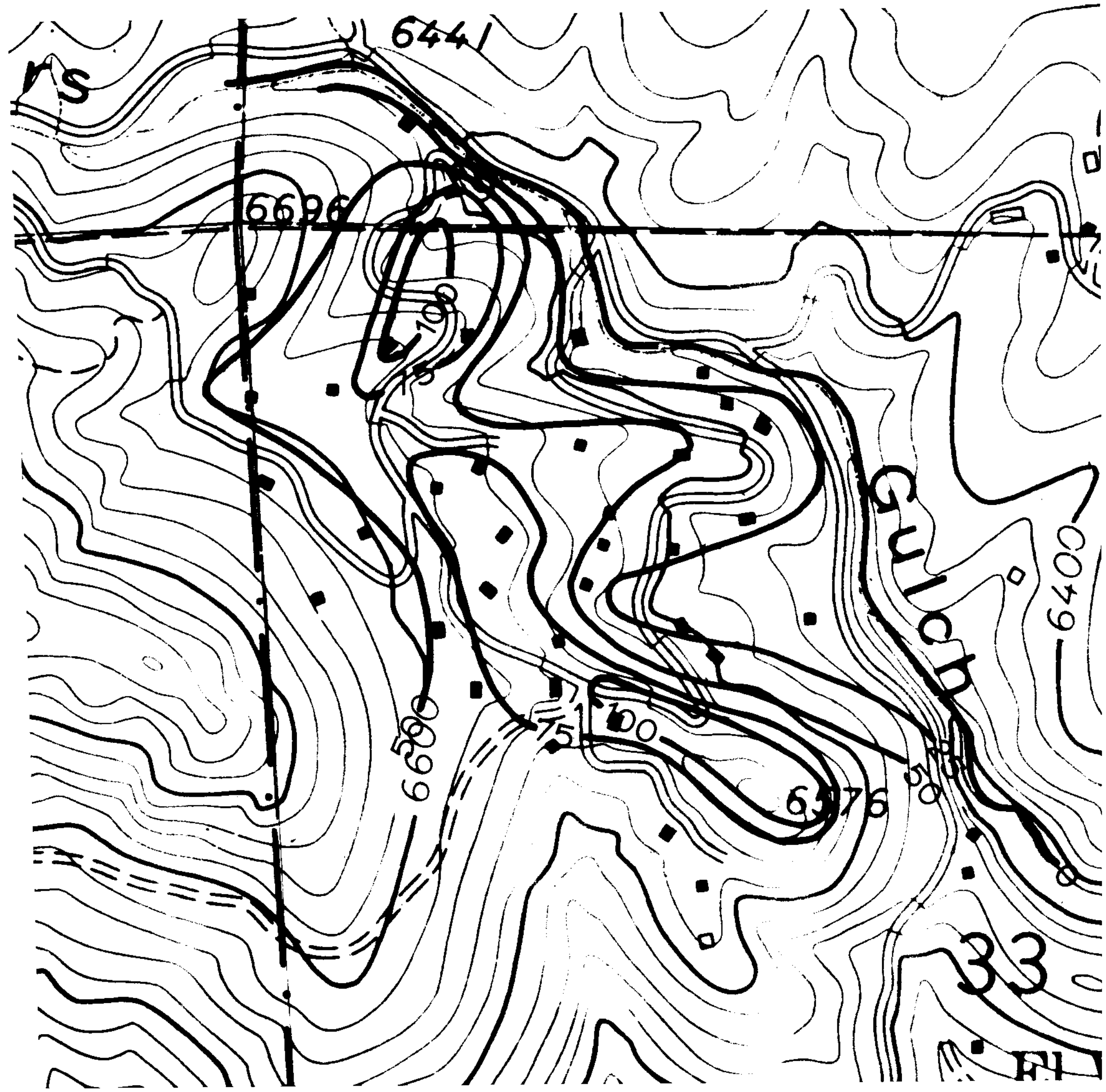


PLATE 13. Overlay indicating water table elevation.

WATER TABLE ELEVATION
TALL TIMBER
CONTOUR INTERVAL 50 FEET

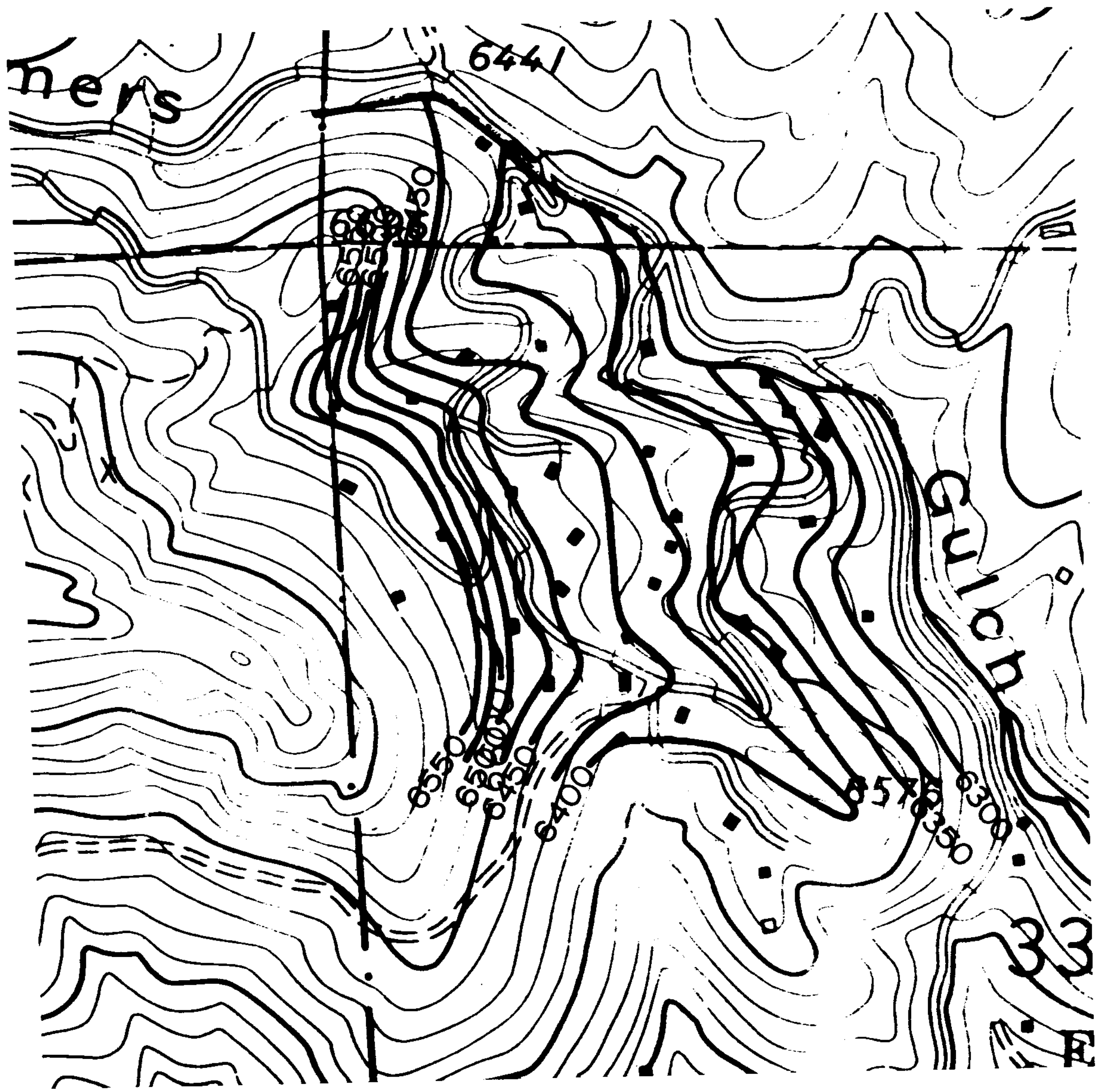


PLATE 14. Overlay indicating zones of intensely weathered bedrock for Tall Timbers. Note - categories for the suitability of weathered bedrock for use as soil absorption systems have not been established.

0 to 5 Feet

5 to 15 Feet

15 or more Feet

WEATHERED BEDROCK THICKNESS
TALL TIMBERS

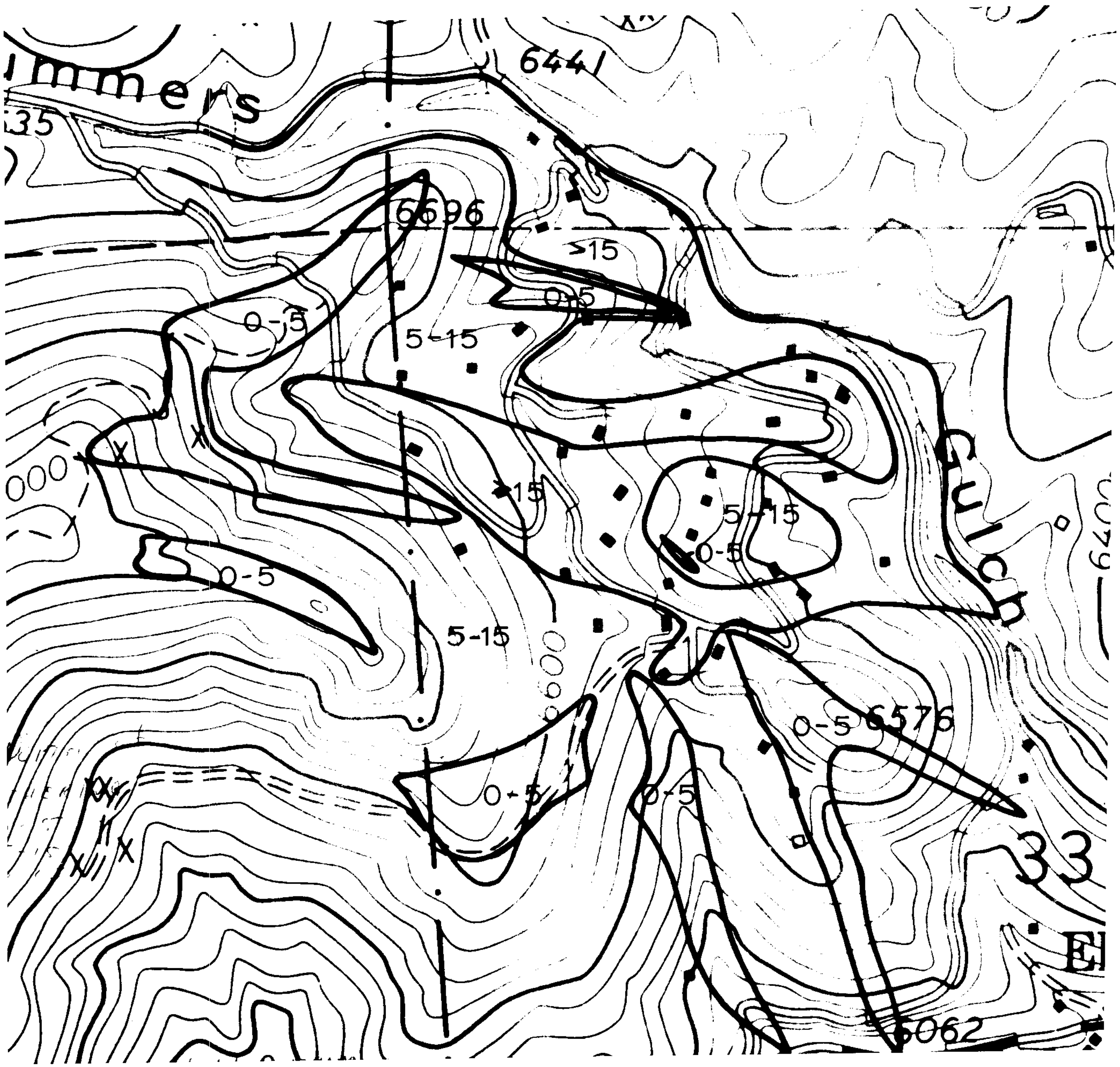


PLATE 15. Overlay indicating zones of different percolation rates for Tall Timbers. Note - all percolation rates of less than 60 min. per inch are acceptable in Boulder County.

less than	10 Min. per inch - Hazardous		
10	to	20 Min. per inch - Safe	
20	to	60 Min. per inch - Safe	
60 or more		Min. per inch - Unsuitable	

PERCOLATION RATE
TALL TIMBERS

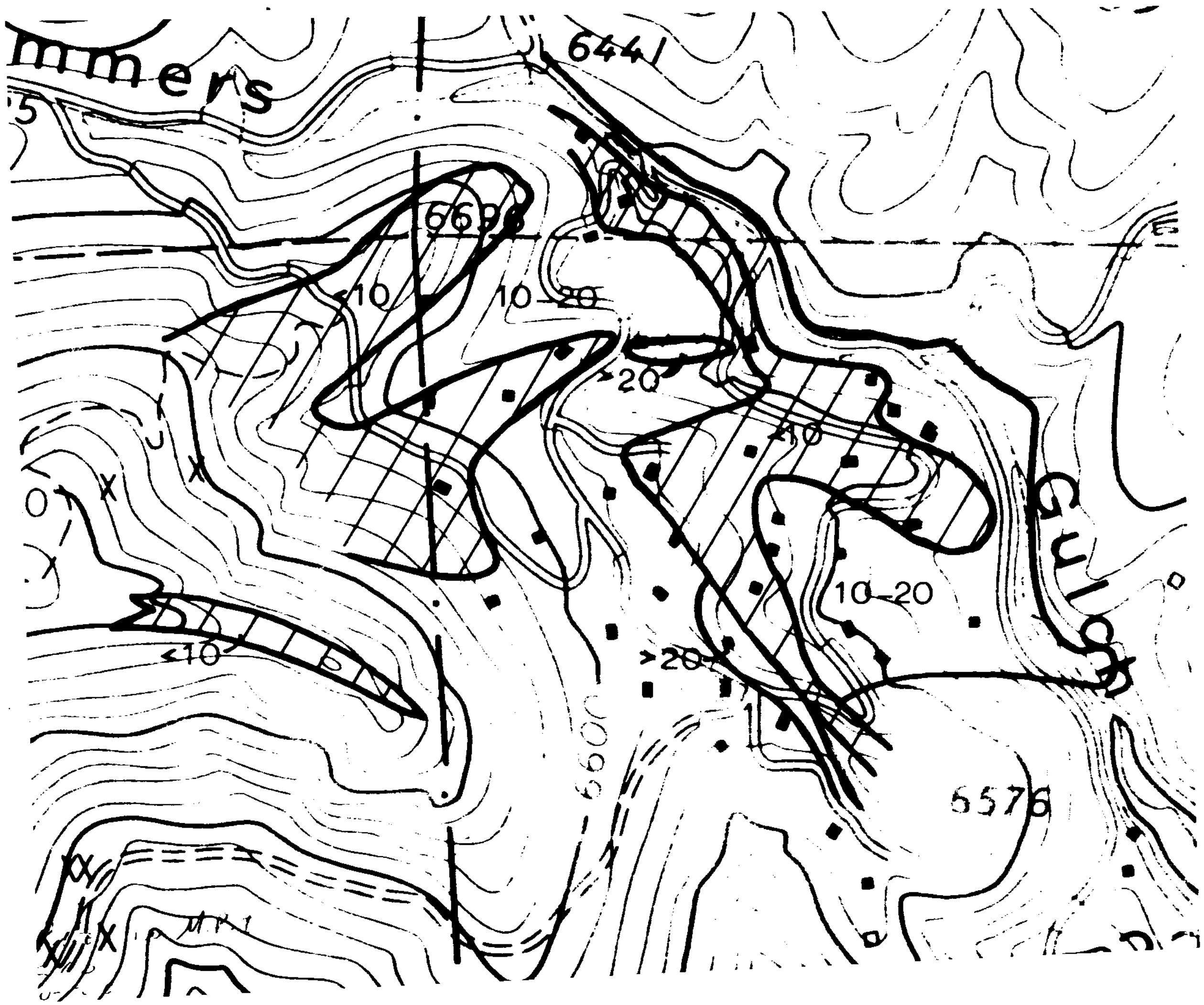
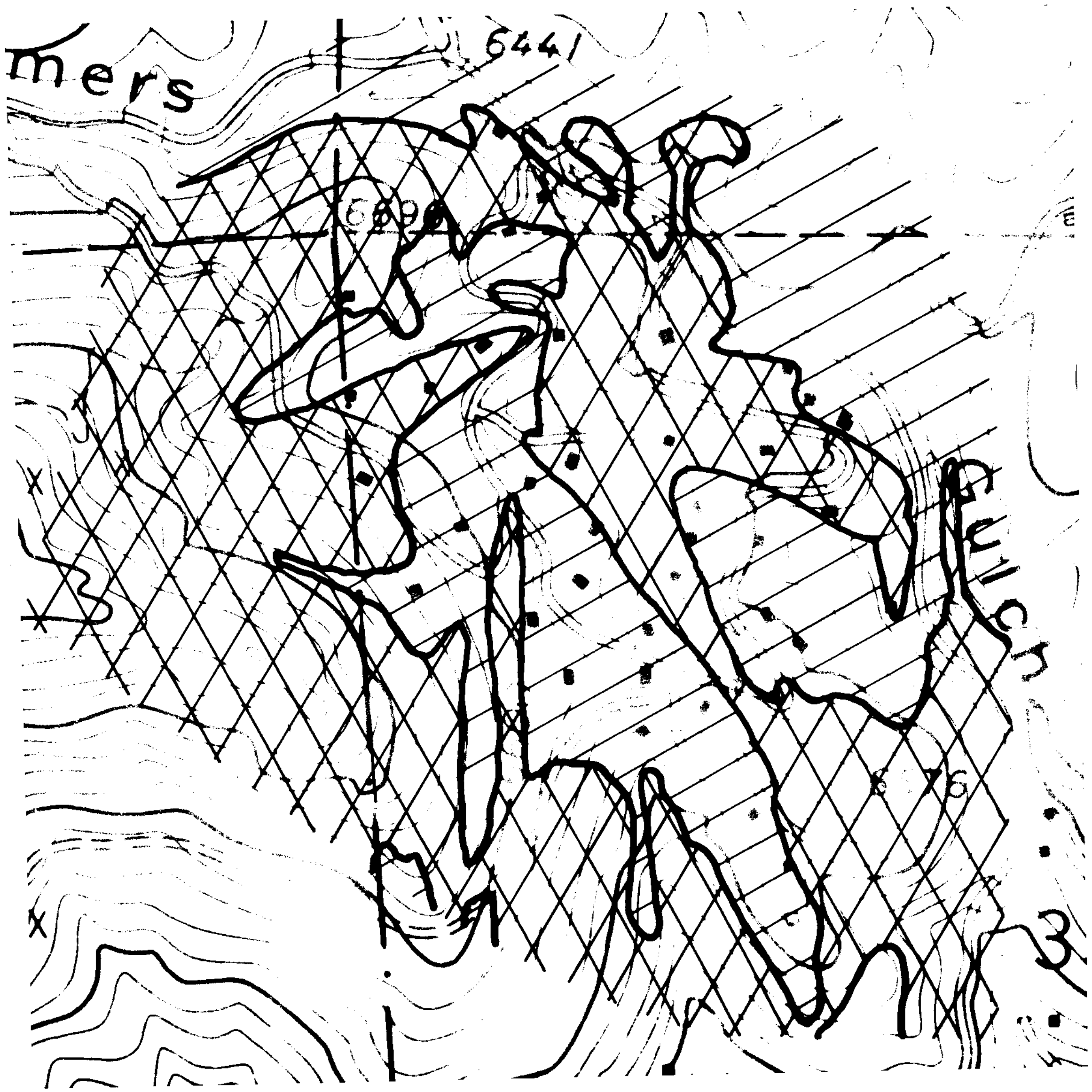


PLATE 16. Composite overlay showing hazardous and unsuitable areas for soil absorption systems for Tall Timbers.

Unsuitable -

Hazardous -

COMPOSITE OVERLAY
TALL TIMBERS



presumably originated during the Precambrian and was later reactivated during Laramide time (Lovering and Goddard, 1950, p. 216). In the study area it is a steeply dipping, poorly cemented zone with some smaller well-cemented zones branching from it. It is an important control on ground water in the area and acts as both a barrier and conduit to the flow of ground water. The major fault zone is shown on Plate 9 and is a poorly cemented, highly fractured zone and acts as a ground water conduit. This is indicated by well yields which are slightly higher in this area and by the chemical tests indicating higher total dissolved solids in this zone because of more intense weathering. An outcrop in the road cut on lower Kelly Road near lot 34 is another indicator of the control exerted on the ground water. This outcrop shows a small, well-cemented branch fault trending to the northwest. On the downhill side the bedrock is moderately weathered while the uphill side is intensely weathered, indicating the well-cemented fault acted as a barrier to the flow of ground water from the uphill side causing a more intensely weathered zone on that side. For these reasons the geologic controls in the Tall Timbers area are very significant.

Glen Haven

The geology of the Glen Haven area is the most varied of the study areas. It is underlain by Precambrian Silver Plume Granite and metasedimentary rocks. Part of the Glen Haven Quadrangle has been mapped by Robert Bucknam (1969). His work was modified by the author to some extent. In general Fox Creek and West Creek are underlain by the younger granitic rocks and the North Fork of the Big Thompson is underlain by metamorphic rocks (see Plate 17).

The granitic rocks are probably equivalent to Silver Plume Granite (Bucknam, 1969) and generally occur as tan, medium-grained, seriate porphyritic quartz monzonite. Average composition if 42 percent quartz, 26 percent microcline, 24 percent plagioclase, 0-3 percent biotite, and 0-12 percent muscovite. Accessory minerals account for less than 3 percent of the total rock and include zircon, sphene, apatite, and opaque minerals. Some chlorite occurs locally as an alteration product of biotite. Foliations and lineations are present in the quartz monzonite and generally occur as alignment and streaking of biotite. Porphyritic varieties of the quartz monzonite occur locally but do not account for large areas near Glen Haven and are included with the coarse-grained variety of Silver Plume Granite for mapping purposes. For the purpose of this report the composition of the coarse-grained variety is the same as the medium grained variety.

There is a broad area where the Silver Plume Granite is intermixed with the metamorphic rocks in such a way that differentiation would be very difficult. This area was mapped as a unit of intermixed quartz monzonite and quartzo-feldspathic mica schist.

Predominant minerals include muscovite, biotite, quartz, microcline, and plagioclase. There are local occurrences of andalusite, cordierite, garnet, and opaque minerals. The percentages of minerals present in any specimen varies widely due to the nature of the mapped unit. This unit is well foliated and mineral lineation is conspicuous and the occurrence of opaque minerals is in concentrations parallel to the foliation.

The metasedimentary unit in the Glen Haven area is mainly a knotted, well foliated, muscovite-biotite schist. Crinkling of the foliation is common and intense in places. Mineralogy varied with metamorphic grade, but muscovite, quartz and biotite were ubiquitous. In addition, chlorite, tourmaline, garnet and andalusite were present locally.

The joints and foliations present in the Glen Haven area each show a preferred orientation that is consistent over the entire area. Joints are well developed and are spaced from 6 to over 20 feet with a preferred orientation of north 30-45^{o} east with dips approaching vertical. The entire area is strongly foliated as evidenced by parallel alignment of minerals. Lineations are predominant in certain areas and are represented in outcrops by fold-axes, boudinage, and mineral alignment either as aggregates or as the elongate minerals themselves. The preferred orientations of the foliations and lineations is north 30-45^{o} west with dips to the southwest from 30^{o} to almost vertical. These alignments are represented as contour diagrams on Schmidt equal area nets (Turner and Weiss, 1963, p. 58) and rose diagrams (Figures 13 and 14).

FIGURE 11. Pole plot diagram of Glen Haven joints.

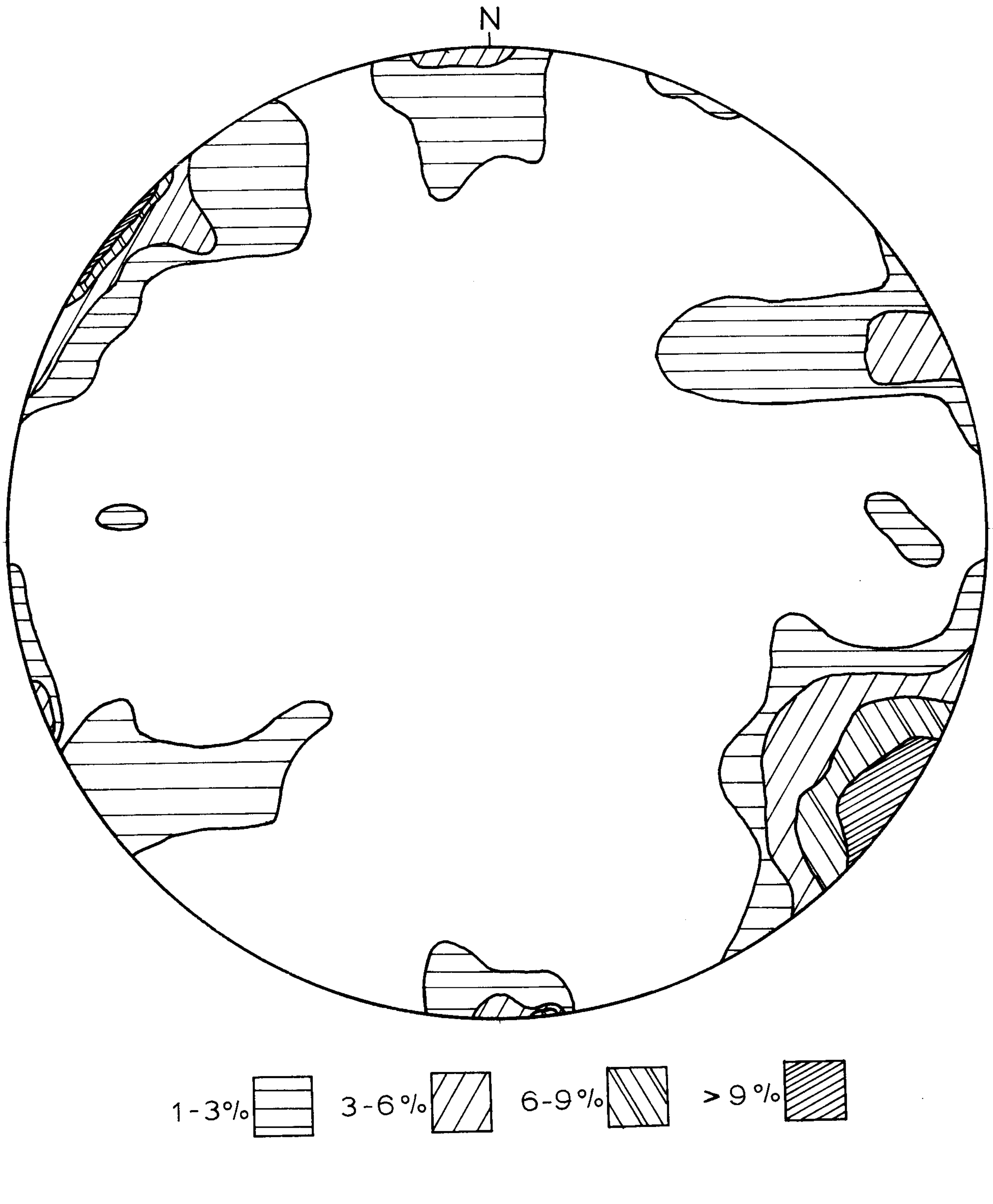

N
1-3%
3-6%
6-9%
>9%

FIGURE 12. Pole plot diagram of Glen Haven foliations.

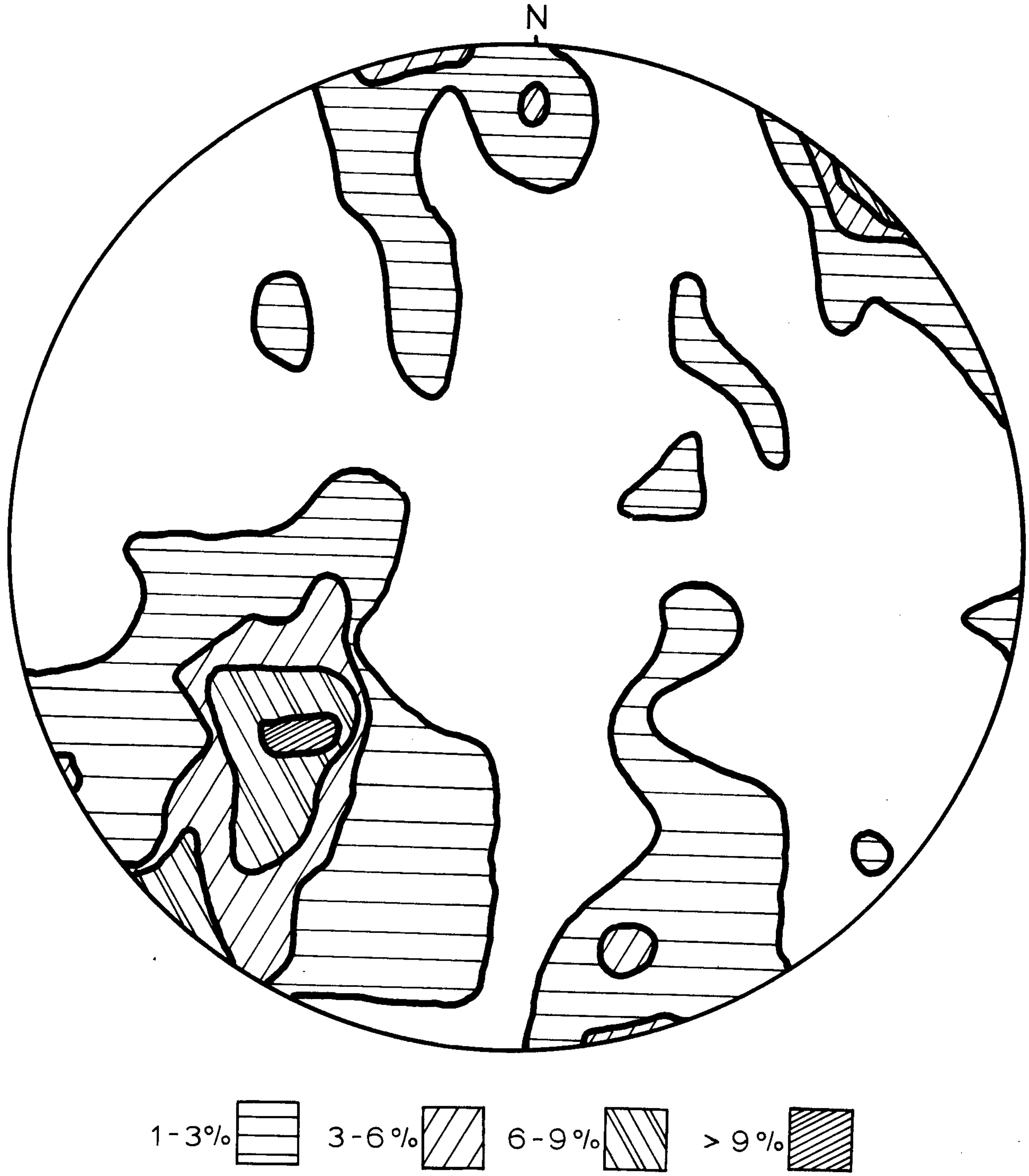

N
1-3%
3-6%
6-9%
> 9%

FIGURE 13. Rose diagram of joints at Glen Haven. Diagram shows the strike direction of the joints with the maximum occurrence equal to 100 percent of the circle radius.

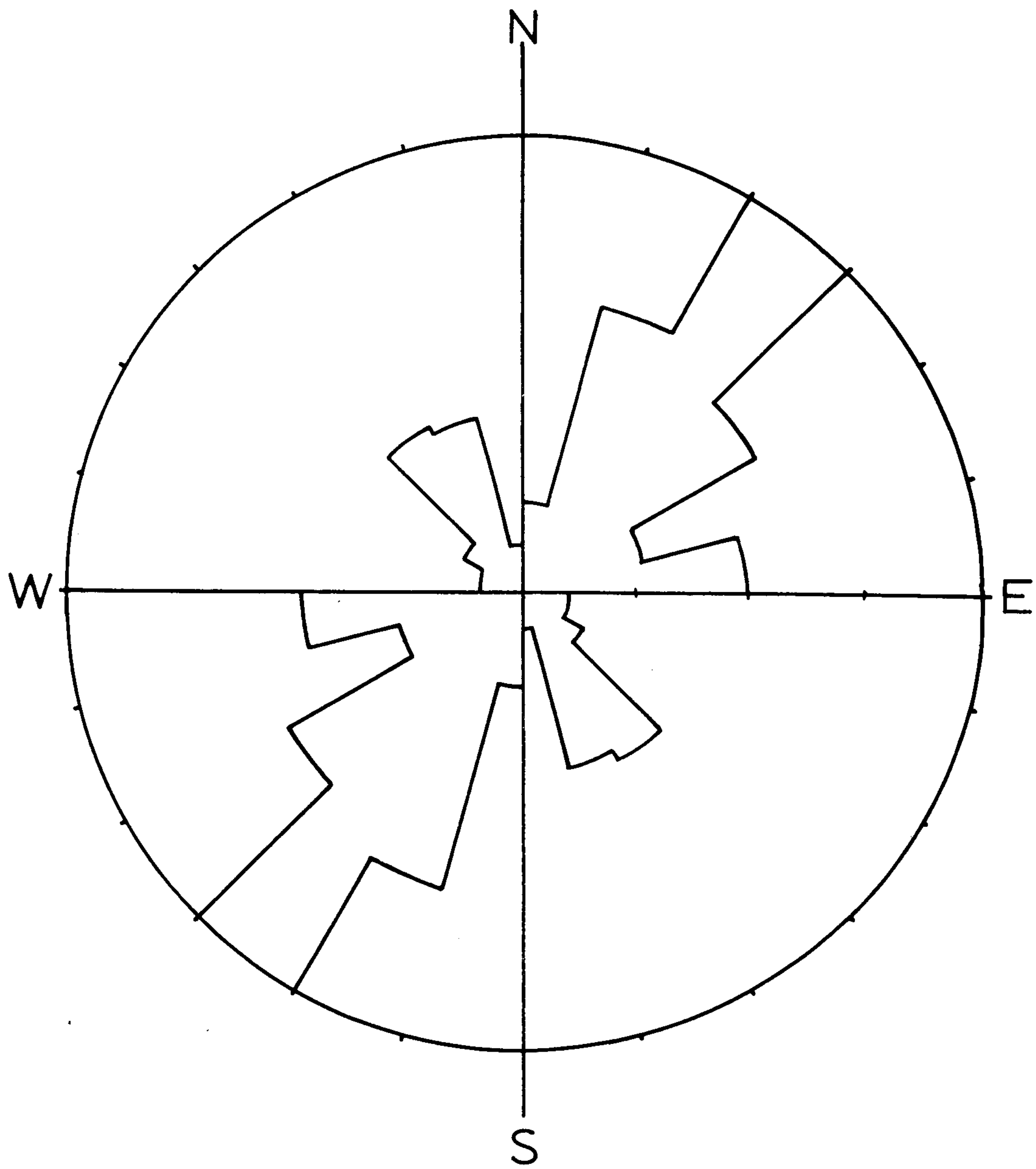

N
W
E
S

FIGURE 14. Rose diagram of foliations at Glen Haven. Diagram shows the strike direction of the foliations with maximum occurrence equal to 100 percent of the circle radius.

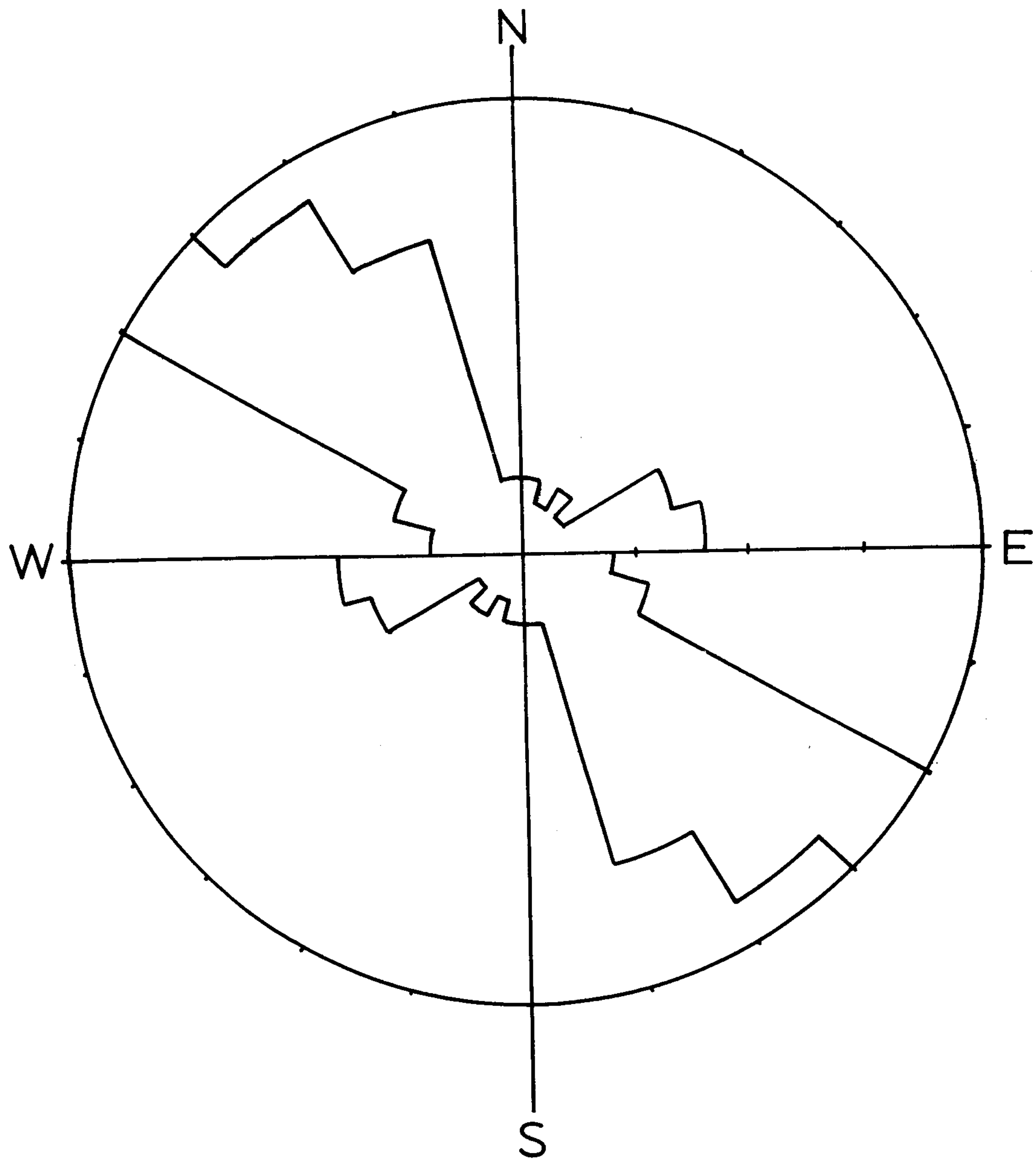

N
W
E
S

PLATE 17. Geologic map of Glen Haven.

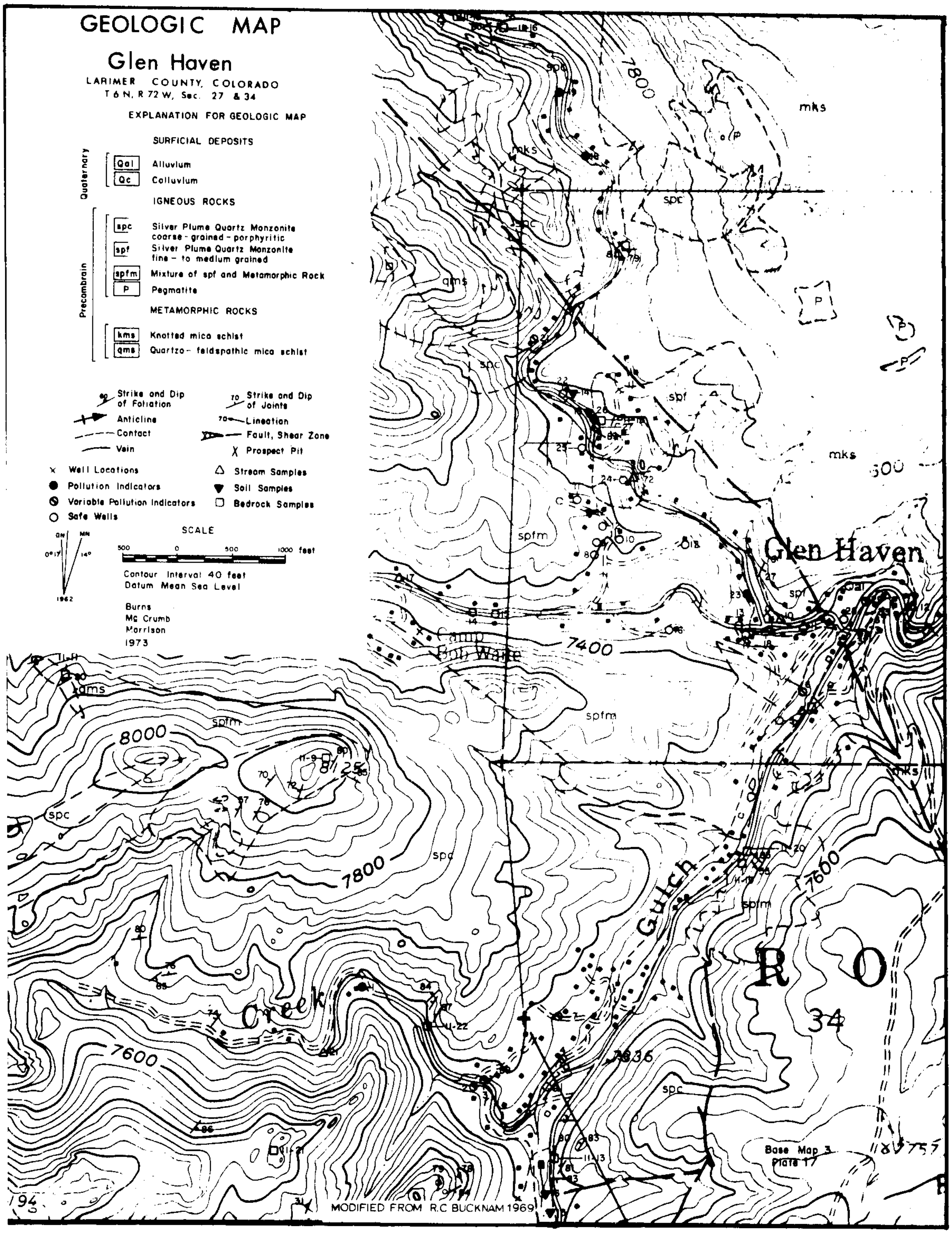
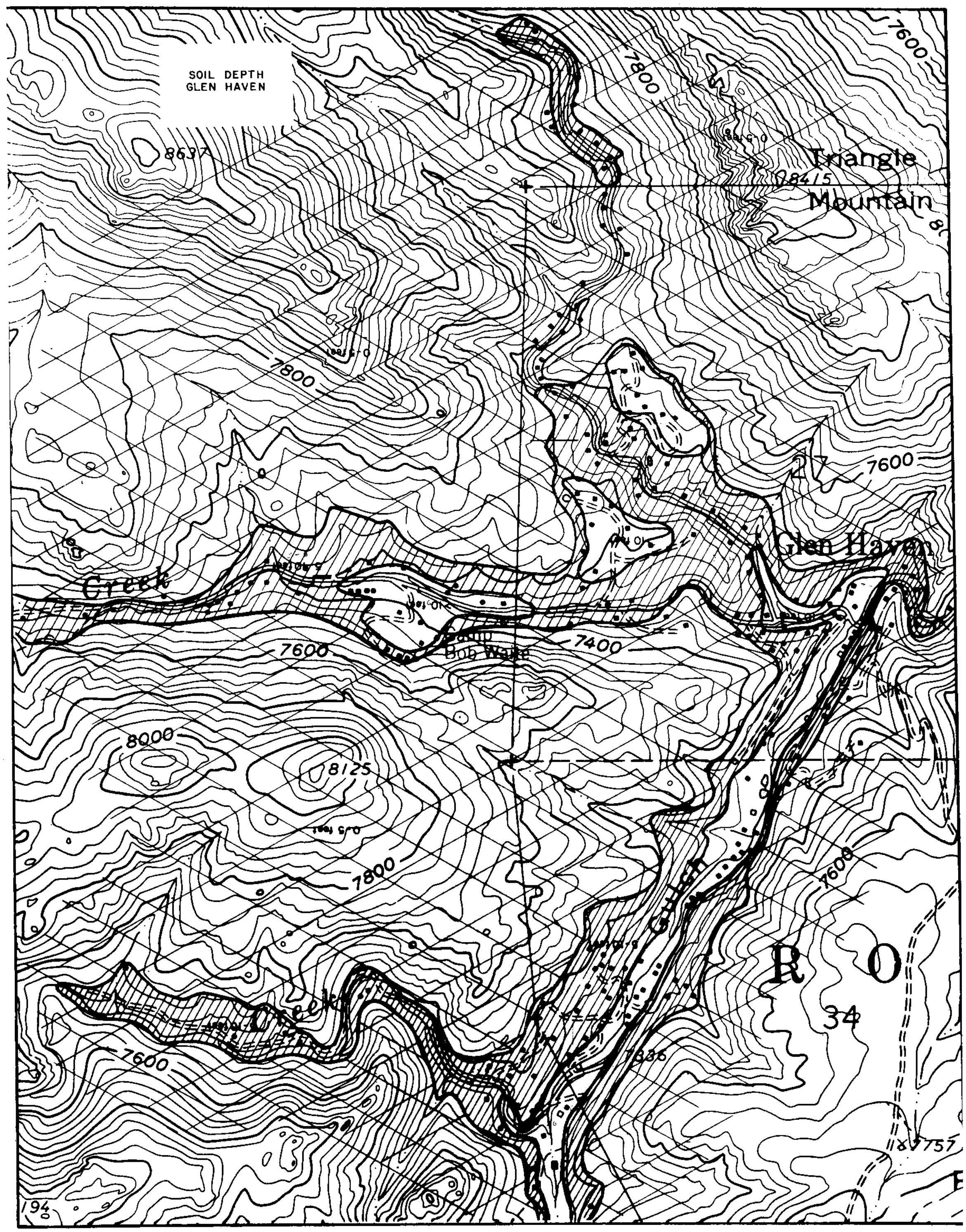

GEOLOGIC MAP
Glen Haven
LARIMER COUNTY, COLORADO
T 6 N, R 72 W, Sec. 27 & 34
EXPLANATION FOR GEOLOGIC MAP
SURFICIAL DEPOSITS
Quaternary
Qal Alluvium
Qc Colluvium
IGNEOUS ROCKS
Precambrain
spc Silver Plume Quartz Monzonite coarse-grained-porphyritic
spf Silver Plume Quartz Monzonite fine- to medium grained
spfm Mixture of spf and Metamorphic Rock
P Pegmatite
METAMORPHIC ROCKS
kms Knotted mica schist
qms Quartzo-feldspathic mica schist
Strike and Dip of Foliation
Strike and Dip of Joints
Anticline
Lineation
Contact
Fault, Shear Zone
Vein
Prospect Pit
Well Locations
Stream Samples
Pollution Indicators
Soil Samples
Variable Pollution Indicators
Bedrock Samples
Safe Wells
SCALE
500 0 500 1000 feet
GN MN
0°17' 14°
1962
Contour Interval 40 feet
Datum Mean Sea Level
Burns
Mc Crumb
Morrison
1973
Glen Haven
Camp
7800
7400
7600
8000
mks
spc
spf
spfm
qms
Gulch
Creek
R O
34
Base Map 3
Plate 17
MODIFIED FROM R.C BUCKNAM 1969

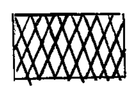
PLATE 18. Generalized rock outcrop and soil depth overlay for the Glen Haven area.

0 to 5	Feet - Unsuitable
5 to 10	Feet - Hazardous
10 or more	Feet - Safe



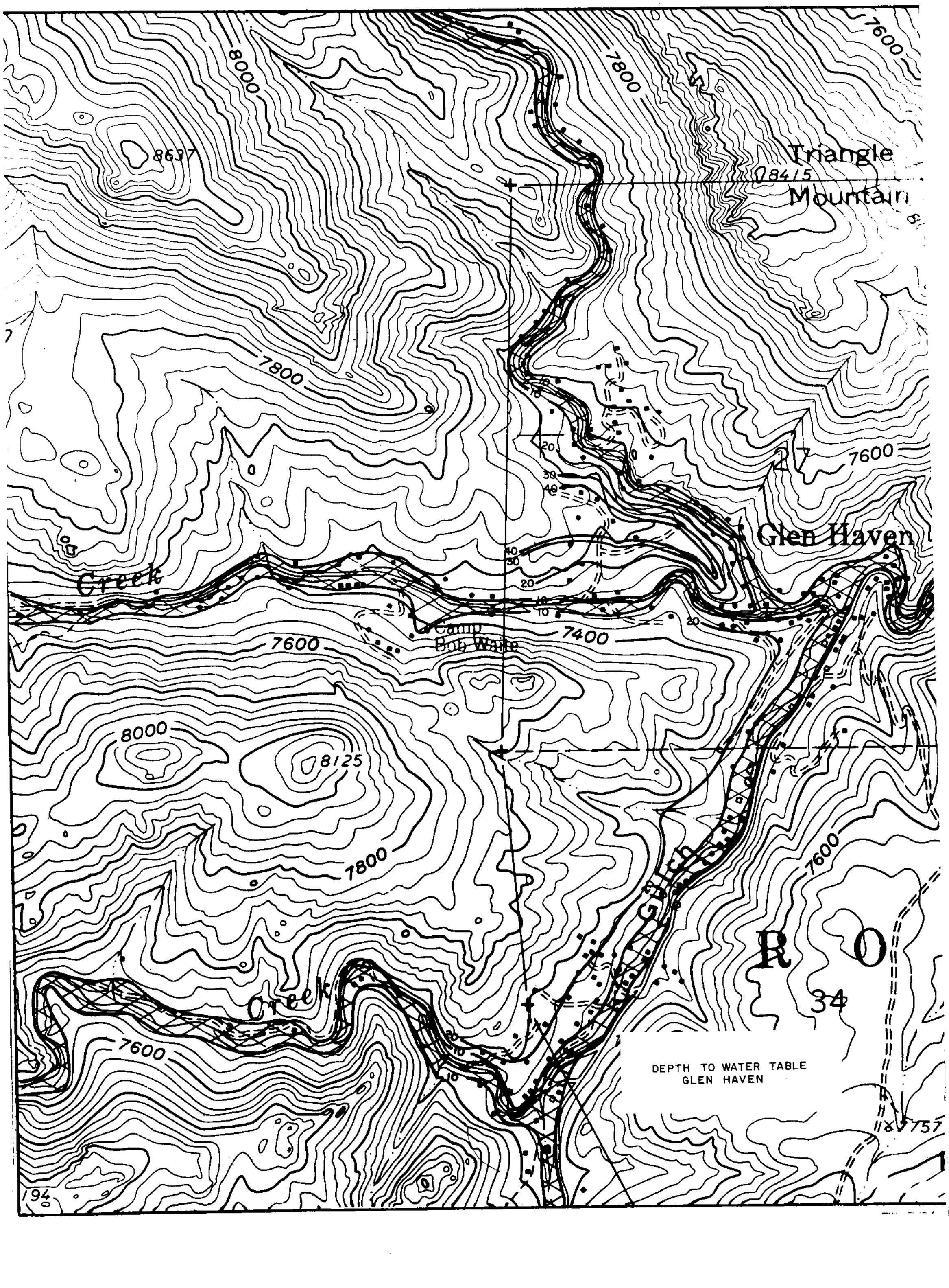
SOIL DEPTH
GLEN HAVEN
8637
Triangle
Mountain
8415
7600
7800
Glen Haven
Creek
Bob Wave
7600
7400
8000
8125
7800
7600
R O
34
Creek
7600
7836
7757
194

PLATE 19. Overlay showing depth to water table in the Glen Haven area. Note - the limited extent of this overlay is due to the lack of control for large areas.

0 to 10 Feet - Unsuitable 

10 to 15 Feet - Hazardous

15 or more Feet - Safe


8000
8637
7800
7600
Triangle
Mountain
8415
Glen Haven
Creek
Camp
Bob Waite
7400
7600
8000
8125
7800
R O
34
Creek
7600
7757
194
DEPTH TO WATER TABLE
GLEN HAVEN

SUMMARY

Each of the study areas is summarized individually as to the effect that each of the evaluated parameters has on the spreading of leach field effluent. Also included in the evaluation is a discussion on the present and future water quality of each area and the effect that development may have on both the quantity and quality of the local ground water supply.

Crescent Park

Water Quality

There are approximately 50 wells located in the Crescent Park area and 36 of these were tested regularly. Two of the wells tested were designated as variable pollution indicators and the remaining 34 wells were not contaminated. The additional wells in the area which were not tested included many which were completed but sealed while home construction was being completed. In addition, several residents were not available during the test period and their wells were not included in the sampling program.

The study indicates that the ground water in the Crescent Park area is unpolluted and will likely remain unpolluted with further development of the subdivision. Reasons for this are:

1) the density of homes will remain low due to the relatively large lot sizes,

2) the effective grain size of the soil is within the most desirable range,

3) the water table is from 6 feet to 200 feet below the ground surface except in two locations where springs occur, (wells in these areas should be monitored very closely, as they are more susceptible to local contamination),

4) the depth of soil and intensely weathered bedrock ranges from 2 feet to 109 feet and appears to be sufficient for soil absorption systems over most of the area, and

5) because it is a relatively new subdivision the construction regulations for homes, wells, and leach fields are more stringent than those which were in effect during the time communities such as Glen Haven were being developed.

Soil

In general, the soils in the Crescent Park area appear to be the best of the areas studied for soil absorption systems. The overall effective grain size is the smallest of the areas, and except for the ridge tops, where the soil is very thin, there appears to be sufficient soil depth for leach fields. There are two areas where the soil thickness between the water table and the projected bottom of a leach field is not sufficient. These occur in areas of a high water table as evidenced by location of the two springs in this area.

The percolation rates for Crescent Park are all within the required limits of 60 min. per inch or less. In addition, except for one rate of 57 min. per inch and four of 10 min. per inch, all fall within the range of 15 to 35 min. per inch indicating a soil texture which is fairly consistent through the area.

X-ray analysis of clays present in the soils indicate that Kaolinite is dominant and occurs in 6 out of 8 samples. Sample 20 has the only example of expansive clay in the Crescent Park subdivision.

Physical Setting

The slope map of the Crescent Park area (Plate 2) shows that much of the area has slopes which are too high for suitable locations for leach fields; however, sufficient areas of lower slopes are present such that portions of most lots in the subdivision have suitable areas for leach-field installation. It should be emphasized that the slope maps derived here are somewhat generalized and on-site slope measurements should be made in making final recommendations for leach field locations for individual cases.

Population density is not a problem in the Crescent Park area because the subdivision is only about 40 percent developed and the lots are generally larger than 2 acres and many are as large as 5 acres.

Age of the development is very important to the operation of septic tank leach line systems because, due to their design, failure is probable during the life of the structure (Franks, 1972, p. 195). The septic tank retains the solids and the leach line disposes of the fluids. When the septic tank reaches the point where it can no longer retain the solids then these, along with the scum which is collected in the tank, begin to enter the leach lines. At this point both the leach line and the filtering media become clogged with the solid particles and the system has failed. Studies have shown that under the best conditions failure occurs after 10 to 12 years of use (Franks, 1972). This problem could essentially be eliminated if home owners would periodically have their septic tanks pumped out; however, most home owners are either not aware that septic tanks require pumping or do not have them pumped until failure occurs. Once a septic tank leach field system has failed, it is likely to fail again and sooner. This is due to the fact that once failure occurs, the soil becomes clogged with solid matter and loses much of its filtration ability.

Geology

The influence local geology has on the spreading of leach field effluent is summarized as follows:

1) The shallow ground water movement in bedrock is influenced to some degree by the faults in the area. In fact, most wells

which are near one of the faults in the area have a higher probability of becoming contaminated.

2) Joints and foliations will control the movement of any water that reaches bedrock. The major trend of the joints and foliations is north 45 to 47° west. The joints and foliations tend to dip very steeply, thus, their control of flow direction will be a resultant of the slope direction and the strike of the joints and foliations,

3) Intensely weathered bedrock occurs in the western part of the subdivision and is associated with the shear zone,

4) The large shear zone which occurs in the western part of the subdivision acts as a conduit to ground water flow as does the small shear zone in the eastern part of the subdivision,

5) The smaller branching faults in the Crescent Park area are well cemented and act as barriers to the flow of ground water,

6) Bedrock mineralogy has little effect on the spreading of pollution, except for the clays produced as natural weathering products.

Tall Timbers

Water Quality

There are approximately 45 wells in the Tall Timbers area and 38 of these were included in our sampling program. Five of the wells tested were designated as variable pollution indicators and six others were categorized as pollution indicators. The remaining 22 wells were not contaminated. The Tall Timbers area, therefore, had 28 percent of the wells tested by our research program as showing signs of contamination.

Our study indicates that the water quality in the Tall Timbers area is not as good as that in the Crescent Park area which had only 8 percent of the wells showing signs of pollution. Also, it is not expected that the water quality will improve due to the following reasons:

1) the density of homes is already relatively high and will become higher with continued development,
2) the effective grain size of the soils is larger than the other study areas, requiring a greater distance for travel of pollution to become properly filtered (see Figure 2),
3) the depth of soil is not sufficient for soil absorption systems in much of the subdivision,
4) the majority of the subdivision is located on steeper slopes than desired for soil absorption systems, and
5) failure may be expected in many of the leach field systems due to septic tanks becoming filled and causing failure in the leach lines. Research has shown that this occurs at about 10 to 12 years under the best conditions (Franks, 1972).

Soil

The soils in the Tall Timbers area are not as well suited for soil absorption systems as those in the Crescent Park area. The effective grain size of the soils in Tall Timbers is in the range .088 mm to .177 mm. While this is larger than the other two areas, it is still well within the range suitable for soil absorption systems. Soil depth is also thinner than that in the Crescent Park area due to the major portion of the subdivision being located on steep slopes. The water table is at sufficient depth over the entire area and ranges from 20 feet to over 100 feet deep, but whether there are sufficient fine-grained filtering soils above the water table is questionable. Percolation rates for the area are more variable than Crescent Park and range from 5 min. per inch to 48 min. per inch. It may be significant to note that from the 30 percolation rates obtained, 18 were 10 min. per inch or less. While this is within allowable limits, it does indicate that effluent will percolate down to the ground water supply much faster than in the Crescent Park area. This is what one would expect for the coarser-grained size of the soils as indicated by the effective grain size. X-ray analysis of clays present in the soils indicated that Kaolinite is the dominant clay in the Tall Timbers area. In addition to the clays analyzed from soil samples, two clay samples present as weathering products in bedrock were analyzed and one was an expansive clay and one a non-expansive clay.

Physical Setting

The slope map of the Tall Timbers area (Plate 10) indicates that most of the area has slopes that are greater than 30 percent and thus leach field-septic tank systems are not well suited for most of the subdivision. It should be noted that a similar large area of unsuitability is indicated by other key parameters as well. This suggests that these parameters are not necessarily independent of each other and that some, such as slope, may be used to predict others, such as percolation rate, soil depth, etc. The fact that leach field-septic tank systems are used in the Tall Timbers area, in spite of the steep slopes and other poorly suited geologic and soil conditions for their use, could be one of the main reasons that the water quality is poorer in the Tall Timbers area than in the Crescent Park area.

The most important non-geologic factor influencing pollution in the Tall Timbers area could be the population density. The subdivision is approximately 50 percent developed now, and 28 percent of the wells tested for this study showed positive counts of coliform. As development continues more ground water pollution can be expected. In addition to the problem of population density is the age of the subdivision. Many of the homes in the area are about 10 to 12 years old, and research has shown that after 10 to 12 years septic tanks become filled with solids causing failure in the leach lines from plugging or anaerobic growth or both (Franks, 1971).

Geology

The influence of local geology on the spreading of leach field effluent in the Tall Timbers area is summarized as follows:

1) The shallow ground water movement in bedrock is influenced to a high degree by the faults in the area. In fact, most wells which show an indication of pollution are located very near the shear zone,

2) Joints and foliations will control the movement of any shallow ground water that reaches bedrock. The major trend of the joints and foliations is north 45 to 60^{o} east. Because both joints and foliations tend to dip very steeply, their control on flow direction will be a resultant of the slope direction and the strike of the joints and foliations,

3) Intensely weathered bedrock occurs in several places in the subdivision and in many places there is sufficient clay present to act as barriers to ground water movement. These are generally associated with the shear zone,

4) The large shear zone, which divides the subdivision in half, acts as a conduit to ground water flow,

5) The smaller branching faults off the large shear zone are well cemented and act as barriers to the flow of ground water, and

6) Bedrock mineralogy probably has little effect on the spreading of pollution, except for the clays produced as natural

weathering products and in connection with the shear zone where they act as barriers to the ground water flow.

Glen Haven

Water Quality

Because many of the residents in the Glen Haven area rely on shallow wells in river alluvium for their water supply and these wells rely on induced recharge from surface waters for their water supply, both surface and ground water were tested in the Glen Haven Area. A total of 29 wells was tested in the Glen Haven area and 8 of these were classified as pollution indicators, 5 were classified as variable pollution indicators, and 16 were classified as not contaminated. Thus 45 percent of the wells in the Glen Haven area show signs of being contaminated. Because it is a resort area many of the homes are occupied only a few weeks out of the year or some years not at all. However, because these wells produce from river alluvium it was felt that even though the well data might be incomplete, a complete sampling of surface water would help in determining the local water quality.

The sampling program for the surface waters in the Glen Haven area included 26 different locations. Tests for total coliform were positive for all locations. Total coliform count increased to some extent at each area where sewage disposal systems began to contribute to the stream. Total coliform count also decreased downstream with dilution. Thus the counts appear to go up and down in total coliform as populated areas are reached. Of the 26 locations sampled 11 were upstream from the influence of Glen Haven, 7 were within the community of Glen Haven, and 8 were from locations downstream of the Glen Haven area. One of the more apparent results of the test program is the correlation between coliform count and seasonal use. For example, the counts were high for all samples on the 7th of July which is right after one of the busiest weekends of the summer and all samples had very low counts during the month of December when very few people are using the picnic areas, and the nearby national park is closed.

This study indicates that the water quality in the Glen Haven area is the poorest of any of the study areas. This was determined from tests on total coliform from all wells tested. Crescent Park had 8 percent of the wells with positive tests, Tall Timbers 28 percent, and Glen Haven 45 percent. It is not expected that the water quality will improve unless many factors which contribute to the water quality are eliminated. Each of the following factors contribute to the poor quality of water in the Glen Haven area:

1) The home density in the summer months will remain high and probably become much higher with time,

2) The water table is very near the ground surface in the valley bottoms where population density is highest and most wells are located,

3) The depth of soil is not sufficient for soil absorption systems on most of the hill sides,

4) The hill sides are generally steeper than the recommended maximum for soil absorption systems, and

5) Because Glen Haven is an old community there are many poorly constructed wells and sewage disposal units, i.e. many residents use privies during the summer months when they occupy their cabins and in most cases these are unvaulted and constructed on fractured bedrock.

Soil

The soils in the Glen Haven area are not well suited for soil absorption systems. The effective grain size of the soils is well within the range suited for bacteria removal (.0625 to .125). However, several other factors indicate that the area is not well suited for soil absorption systems. For example, hill slopes in the area are very steep and in general have thin soil covers. In areas such as on the valley alluvium where there is a thick soil cover, the water table is very shallow. X-ray analysis of the clays present in the soils at Glen Haven show a higher occurrence of expansive clays than the other study areas. Ten soil samples were taken at Glen Haven and 5 had expansive clays present. In addition to the above facts, the surface waters in the Glen Haven area already show signs of being highly contaminated. This would make overloading of the ground water system much easier than in other areas. Also, it appears that the surface waters rely somewhat on downstream dilution for removal of some of the bacteria and additional leach fields in the Glen Haven area as development increases will only add to the already contaminated streams.

Physical Setting

Many non-geologic factors contribute to the pollution problem in the Glen Haven area. For example, sewage disposal methods range from the standard septic- tank leach-field system to many unvaulted privies which are used during the summer months. Also significant is the fact that most of the summer cabins are located very near the streams and because of this so are their privies. Population density is another non-geologic factor influencing the pollution. During the summer months when the population is at its highest, the demand on the ground water system is the greatest, and infiltration from leach fields and privies is also the greatest. Thus the problem for Glen Haven, in addition to further growth and development, is stopping the overloading of the ground water system during the summer months. This means eliminating the poorly constructed unvaulted privies and moving all sewage disposal systems further away from the streams.

This will be especially difficult in the Glen Haven area because the areas away from the streams are also not suitable for sewage disposal systems.

Geology

The influence that the local geology has on the spreading of leach field effluent is summarized as follows: In general, soil absorption systems are not satisfactory in the Glen Haven area due to shallow soil depths, high water table, steep slopes, and the possibility of overloading a system which is already polluted. However, if soil absorption systems are used, the following can be expected:

1) Foliations are well developed and show a major trend as indicated in Figures 8 and 10; however, due to their closed nature, very little ground water enters the foliations,
2) Joints are also well developed and open enough to allow ground water movement in the direction of the dips (Figure 7) should water enter the fractures,
3) There are very few areas of intense weathering in Glen Haven, and water which percolates through the soil does not penetrate as deeply into the unjointed bedrock as the other study areas,
4) Because of the unweathered nature of the bedrock, the dikes and faults in the area do not have a large influence on ground water movement. There is one large well cemented fault in

the Glen Haven area; however, it appears to have little effect on the flow of ground water, and

5) Bedrock mineralogy has little effect on the spreading of pollution in the areas studied.

DISCUSSION

That a definite relationship exists between several geologic parameters and the occurrence of ground water and surface water pollution is shown by the results of this report. This conclusion is supported by previous studies (Romero, 1970; Frank, 1971, 1972a; Waltz, 1972; Allen and Morrison, 1973) which have also investigated the relation between geology and groundwater pollution. Each parameter used to evaluate the pollution potential of an area is listed below and the method in which the parameter is used is discussed.

An area is considered as either safe, hazardous, or unsuitable for soil absorption sewage disposal systems for data given for each parameter considered separately, and the area is also evaluated as either safe, hazardous, or unsuitable for soil absorption sewage disposal systems using a combination of all parameters.

The categorizing of the areas as either safe, hazardous, or unsuitable is somewhat arbitrary, but only in the selection of the quantitative boundaries of the various categories. Statistical analysis given in this report as well as independent practical and theoretical studies (Orlob and Krone, 1956; Romero, 1970; Franks, 1971, 1972a; Allen and Morrison, 1973) support the conclusions on the effect of the parameters considered and indicate the limits for the various categories are reasonable.

A category of "safe" designates areas which can be developed following present regulation governing mountain subdivisions in Colorado (i.e., those regulations stated in the 1973 Senate Bill 35 of the State of Colorado).

A category of "unsuitable" designates areas which will not support a soil absorption sewage disposal system. Areas of this category should not contain any disposal system of this type if the quality of the ground water is to be preserved. They are areas of extremely high pollution potential.

An intermediate category of "hazardous" designates areas which have a fairly high pollution potential, but which might support a soil absorption system for sewage disposal for special situations (e.g., very low density of dwellings). The local geologic features need to be considered very carefully before areas in this hazardous category are developed.

Parameters and limits of suitability:

1. Slope

0 to 20 percent	safe
20 to 30 percent	tentatively considered suitable*
30 or greater percent	unsuitable

---

*Slopes of 20-30 percent are considered safe since there was no significantly higher pollution in wells located on slopes of 20-30 percent than those on slopes of 0-20 percent. It should be noted that some investigators consider any slope above 20 percent unsuitable for leach fields (Franks, 1971). When other areas are analysed, it may be that the 20-30 percent slope class will be removed from the safe category and have to be considered as either hazardous or unsuitable.

2. Depth of Soil (not including weathered in situ bedrock)

   10 feet or greater . . . . safe
   5 to 10 feet . . . . hazardous
   less than 5 feet . . . . unsuitable

3. Depth to Water Table or Impervious Layer (this assumes that the leach field is not deeper than about 3 feet and that suitable filtering material (soil) exists between bottom of leach field and water table)

   15 feet or greater . . . . safe
   10 to 15 feet . . . . hazardous
   10 feet or less . . . . unsuitable

4. Percolation rate (current regulations are generally sufficient for percolation rates providing that values for other parameters are suitable - an exception is listed for very rapid percolation rates). Typical percolation rates that are currently acceptable:

   10 min. per inch to 60 min. per inch . . . safe
   (in soils with non-expansive clays)

   10 min. per inch to 40 min. per inch . . . safe
   (in soils with expansive clays)

   5 to 10 min. per inch . . . . hazardous

   less than 5 min. per inch . . . . unsuitable

   greater than 60 min. per inch . . . . . . unsuitable
   (non-expansive clays)

   greater than 40 min. per inch . . . . . . unsuitable
   (expansive clays)

Perhaps a better parameter to consider than percolation rates would be effective grain size, especially since the currently prescribed methods for measuring the percolation rates are poorly defined and give imprecise results. Not enough data is available relating to effective grain size to the filtering efficiency of a soil for quantitative limits to be established in this report, however,

A fifth factor which should possibly be included in the analysis of an area is the depth of weathered bedrock. At present no reliable data exist for evaluating the effect of weathered bedrock as a filtering media for sewage effluent, therefore incorporation of this parameter into our evaluation scheme is not possible at this time. If reliable data can be obtained for the limits of suitability of weathered bedrock, incorporation of this parameter into the scheme should be relatively straight forward.

Several other factors in addition to the parameters listed above must also be considered in estimating the suitability of an area for use of soil absorption type sewage disposal systems. Unfortunately, most of these additional factors are not as readily quantifiable as the four key factors listed above.

In order to minimize the probability of polluting surface water supplies, leach field areas should be a minimum of 100 feet from rivers, streams, lakes, and wells. There should be a minimum of 15 feet of soil horizontally from any construction cut or slope above a construction cut. Open gravel areas with a high water table, such as might occur near old stream courses, are unsuitable in all cases.

The location and trend of any special geologic feature, such as a major joint or joint set, fault, shear zone, igneous dike, unconformity, etc., should be noted and the distances between a leach field area and all special geologic features should be determined. As these special features can act as both barriers or conduits for ground water and/or sewage effluent, their locations can be of crucial importance in evaluating an area for pollution potential, and each case must be considered separately as the possible effects are too numerous for adequate generalizations. It is evident from the present study that local geologic features can play a dominant role in the pollution potential of a mountainous area.

Non-geologic and non-geomorphic factors that must also be considered in evaluating the pollution potential of a site include the method of sewage disposal, population density on the site, age of the development, and type of construction of wells, sewage disposal facilities, roads and homes.

Presentation of Critical Data

A major problem in the application of geologic and geomorphic data to an analysis of a given area is how the data, once collected, is to be utilized. The presentation of data on a suitable base map such as the topographic base maps used in this study is one of the most useful methods of presentation for purposes of land-use planning, and has the further advantage of being readily interpreted by qualified engineers, scientists, and technicians from varied disciplines. Interpretation of the geologic map of the area would most likely require a trained geologist or geological engineer, however, and may also require some on-site inspection.

The scheme of evaluation and data presentation used here utilizes transparent overlays for a suitable base map, e.g. a topographic map of suitable scale, showing the parameters of slope, soil depth, water table depth, percolation rate, and depth of bedrock weathering, respectively. On each overlay, safe, hazardous, and unsuitable areas may easily be delineated. In addition, a composite map showing, for example, the areas considered unsuitable for all parameters combined is easily derived.

The interpretation of the composite map in areas indicated as hazardous by two or more parameters is more difficult. The statistical analysis of the correlation of pollution occurrence with a combination of individual parameters indicates that individual parameters may have a rather low correlation (expressed as r^2) in with pollution in the hazardous areas, but that combining the parameters may show that the correlation of several parameters indicating hazardous areas with pollution is high ($r^2 \approx .85$). It is recommended here than an area indicated as hazardous in two or more parameters be considered unsuitable for dispersal type sewage disposal systems.

In addition to the overlay maps of the various parameters, it is essential to construct an overlay map of the geology of the area. The location and nature of special geologic features such as faults, shear zones, unconformities, igneous dikes, etc. must be considered in evaluating the pollution potential of an area, as they may act as loci of discontinuities in the overlay maps showing the quantified data on the parameters, and these discontinuities are not always evident from the overlay maps showing only the parameters due to sparcity of data points near the geologic features or discontinuities. In some areas there will be strong correlation between bedrock types and various pollution problems and ground water movement. This was not the case in the mountainous areas studied in this report, but the correlation has been well documented elsewhere (e.g., for sedimentary rocks including limestone, Parizek, White, and Langmuir, 1971; for basalts, Stearns and MacDonald, 1942; for pyroclastic rocks, tuffs, ash, and breccias, Davis and De Wiest, 1966, Chapter 9).

In areas of crystalline plutonic bedrock such as occurs in the areas studied and throughout most of the Front Range of Colorado, there is little filtering effect of bacteria from sewage effluent once the effluent gets into the fracture system of relatively fresh rock (Allen and Morrison, 1973). Once unfiltered sewage reaches the unweathered bedrock, the probability that the ground water will become polluted is very high, and only in exceptional cases does further filtering take place sufficiently to remove these bacterial pollutants from the ground water. It is common to have the polluted ground water confined to certain fracture systems, and in special cases this polluted ground-water can be avoided by carefully selecting the site of a well (Millon, 1970; Waltz, 1972). In order to avoid pollution of all ground water, an evaluation scheme, such as the one used here, which attempts to avoid having any sewage bacteria enter the ground water system via rock fractures, must be employed.

Additional overlay maps could be generated from data on population density, effective grain size of soil, landslide deposits and potential landslide areas, water courses and areas inundated by floods, areas containing swelling clays, etc. which, while all not being critical for the evaluation of water pollution potential from sewage systems, would be useful in a total land-use planning approach to the analysis of an area.

CONCLUSIONS

1. Ground water pollution from ineffective sewage disposal systems occurs in areas which meet all present requirements governing mountain home construction; therefore, the present requirements for location and installation of sewage disposal systems are not adequate.

2. Local geologic features often play a dominant role in shallow ground water movement and in the movement of sewage effluent.

3. Location and nature of these geologic features must be carefully determined to assess the pollution potential from sewage of a given area.

4. Certain parameters can be quantified and used singly and together to evaluate the pollution potential of a given area. These parameters are slope, depth of soil, depth of water table and percolation rate.

5. The system of analysis of a given area using the local geology and the four parameters may be used in small or large scale planning of an area or areas in mountainous terrain, and the analysis will provide information as to the suitability of sites for installation of dispersal type sewage disposal systems.

6. Percolation rates that are too high (less than 10 min. per inch) indicate that a leach field site is unsuitable just as percolation rates that are too low (greater than 60 min. per inch) does under most current regulations.

7. When several of the quantified parameters indicate that an area is hazardous for proper leach field operation, the area should be considered unsuitable for location of leach fields.

8. Shallow wells which are close to streams or other surface water and produce from alluvial fill often reflect the water quality of the surface water, and due to induced ground water recharge from the surface water the wells may be contaminated by the surface water.

9. The effective grain size of soils in the mountain areas studied did not vary significantly when taken from areas of similar slope; however, the effective grain size did vary between areas of different slopes.

10. The bedrock mineralogy and petrography was fairly similar in the three study areas, and had little apparent effect on the spreading of bacterial pollutants from leach field effluent.

11. Clay mineralogy of the soils tested was fairly similar in the three study areas and had little apparent effect on the spreading of bacterial pollutants from leach field effluent.

Further Investigations

Further research in certain areas is indicated by the results of this study. These further studies would extend the current study and help test some of the conclusions therein:

1. The correlation between slope and other parameters such as soil depth, effective grain size of soil (or percolation rate) and depth of weathering of bedrock should be determined in an intensive statistical study.

2. On-site tests measuring the effectiveness of weathered rock as a bacterial leaching agent should be performed in order to incorporate the data on depth of weathering into the scheme outlined here for evaluation of pollution potential in mountainous regions.

3. The bacterial filtering properties of soils with different effective grain size and different soil depth should be determined for soils from mountains terrains. If possible, this should be done both in the lab and in on-site tests.

4. The effect of temperature on the persistance and spread of bacteria and viruses should be determined as much of the available data is for restricted temperature ranges.

5. Long term changes (2-10 years) in the water table due to leach field operations should be studied. Such factors as water table depth can be changed significantly.

6. The physical and chemical changes in soils and weathered bedrock due to long term exposure to sewage effluent should be studied. This study should include what changes have occurred in the percolation rate of fluids in the soils and the bacterial filtering capacity of the soils.

7. A method for predicting the quantitative parameters used in the analysis proposed here using faster and less expensive techniques should be developed. Because many of the properties are interdependent on underlying geologic features (including bedrock type), microclimate, and geomorphic features, development of rapid techniques to evaluate at least some of the parameters would seem feasible.

REFERENCES CITED

Allen, M. J., 1972, Bacterial Movement Through Fractured Bedrock. Ph.D. Thesis, Colorado State University, Fort Collins, 111 p.

Allen, M. J., and S. M. Morrison, 1973, Bacterial Movement Through Fractured Bedrock, Ground Water, Vol. 11, No. 2, p 6-10.

Bailey, E. H. and R. E. Stevens, 1960, Staining to Determine Potash and Soda, Amer. Mineralogist, v. 45, p. 1020-1025.

Boos, C. M., and M. F. Boos, 1957, Tectonics of Eastern Flank and Foothills of Front Range, Colorado, A.A.P.G., vol. 41, No. 12, p. 2603-2676.

Bucknam, R. C., 1969, Structure and Petrology of Precambrian Rocks in Part of the Glen Haven Quadrangle, Laramie County, Colorado, Ph.D. Thesis, University of Colorado, Boulder.

Carroll, Dorothy, 1970, Clay Minerals: A guide to their X-ray Identification, Special Paper #126, Geological Society of America. 80 p.

Deutsch, M., 1965, Natural Control Involved in Shallow Aquifer Contamination. Groundwater, vol. 3, No. 3, p. 37-40.

Franks, Alvin L., 1972, Geology for Individual Disposal Systems. California Geology, vol. 25, No. 9, p. 195-203.

________, 1972, Geologic Characteristics of Leach Field Areas for Septic Tank Installation. Proc. Contract Service Sanitarians, March 16, 1972, Lake Tahoe, California.

________, 1971, Practical Geologic Considerations for Determining Suitable Locations for Individual Sewage Disposal Systems. Proc. Am. Soc. of Civil Engineers, Nov. 11, 1971, San Bernardino/Riverside, California.

Freethey, G. W., 1969, Hydrologic Evaluation of Pollution Potential in Mountain Sites. M.S. Thesis, Colorado State University, Fort Collins.

Ganow, H. C., 1969, Expansive Clays in the Benton Formation. M.S. Thesis, Colorado State University, Fort Collins.

________, 1969, X-ray Diffraction Analysis of the Less than Two Micron Fraction, of Seven Samples Collected near Prairie Divide, Colorado. Unpublished Report.

Gardner, Maxwell E., 1968, Preliminary Report on the Engineering Geology of the Boulder Quadrangle, Boulder County, Colorado. U.S.G.S., Open File Report.

________, 1968, Preliminary Report on the Engineering Geology of the Eldorado Springs Quadrangle, Boulder and Jefferson Counties, Colorado. U.S.G.S., Open File Report.

Lovering, T. S., and E. N. Goddard, 1950, Geology and Ore Deposits of the Front Range Colorado, U.S.G.S. Prof. Paper No. 223.

Millon, E. R., 1970, Water Pollution, Red Feather Lakes Area, Colorado. M.S. Thesis, Colorado State University, Fort Collins.

Orlob, G. T., and R. B. Krone, 1956, Final Report on Movement of Coliform Bacteria Through Porous Media. Sanitary Engineering Research Laboratory, Univ. of Calif., Berkeley, Calif., U.S.P.H.S. Grant 4286.

Romero, J. C., 1970, The Movement of Bacteria and Viruses Through Porous Media. Groundwater, Vol. 8, No. 2, p. 37-48.

Turner, F. J. and L. E. Weiss, 1963, Structural Analysis of Metamorphic Tectonites, McGraw-Hill, New York. 545 p.

United States Public Health Service, 1967, Manual of Septic-tank Practices. Public Health Service Pub. No. 526.

Walton, W. C., 1970, Ground Water Resource Evaluation, McGraw-Hill, New York, 664 p.

Waltz, J. P., 1972, Methods of Geologic Evaluation of Pollution Potential at Mountain Homesites, Ground Water, Vol. 10, No. 1, p. 42-49.

Wells, John D., 1965, Geology of the Eldorado Springs Quadrangle, Boulder and Jefferson Counties, Colorado. U.S. Geol. Survey Bull. 1221-D.

Wrucke, C. T., and R. F. Wilson, 1967, Geologic Map of the Boulder Quadrangle, Boulder County, Colorado. U.S.G.S. Open File Report.

APPENDICES

Explanation of abbreviations and symbols used in following tables.

d-90	Equivalent to effective grain size, range in sieve analysis which included the size where 90 percent is coarser and 10 percent finer by weight.
P.I.	A well categorized as a pollution indicator because the total coliform count was more than 1 per 100 ml consistently.
V.P.I.	A well categorized as a variable pollution indicator because the total coliform count varied from more than one to less than one per 100 ml during the sampling period.
S	A well categorized as safe because the total coliform count was less than one consistently during the sampling period.
TNTC	Indicates a total coliform count on a water sample which was greater than 300 and thus categorized as to numerous to count.
Cl	Indicates a well which was chlorinated by the owner due to a previous unsafe test.
cb	Indicates a soil sample which was obtained by use of a core barrel.
a	Indicates a soil sample which was obtained by collecting sample directly from the auger blades.
TDS	Chemical test indicating total dissolved solids as $CaCO_3$ in parts per million (ppm) as determined by conductivity methods.

APPENDIX 1. Mode (volume percent) of crystalline rocks in all study areas.

TABLE 1. Modes (volume percent) of bedrock samples from all study areas. Modes by visual estimates using petrographic microscope, microcline and plagioclase distinguished by point counts after staining by the procedure of Bailey and Stevens (1960).

Sample Number	Quartz	Microcline	Plagioclase	Biotite	Muscovite	Hornblende	Accessories	Chlorine
			Crescent Park					
13-1	34	28	34	3	Tr		1	Tr
13-2	31	24	38	7	Tr			Tr
13-4	34	24	33	4	1			Tr
13-6	29	35	34	3			2	
			Tall Timbers					
12-1	32	23	38					12
12-2	30	58	8		1		3	
12-3	30	3	43	17		4	3	
12-4	16	5	44	2		32	1	
12-5	20	20	33	3		4		
12-7	36	30	25	6			3	
12-9	43	21	27				8	
			Glen Haven					
11-7	16	20	19		23	18		4
11-9	42	26	24	3	4		1	
11-11	20		19	32		29	1	
11-13	25	20	54		Tr		1	
11-15	12	24			35	24	5	
11-16	20	35	14				2	29
11-18	28	19	38		12		3	

APPENDIX 2. Data for individual home sites as determined by drillers well logs and percolation rates for individual lots obtained from county health department records.

TABLE 1. Measurements at individual home sites as determined from drillers well logs and percolation rates for individual lots obtained from county health department records of Jefferson County.

Lot Number	Depth of soil-ft.	Depth of weathering-ft.	Static water level-ft.	Well depth-ft.	Well yield in gal./min.	Percolation rate in min./inch
			CRESCENT PARK			
2	2	35	90	260	6	24
3	1	27	40	125	2	
4	3	35	18	320	.5	
5	3	80	30	200	2	20
6		3	40	170	1.5	
7	3	109	32	125	5	40
9a		6	15	200	1	27
9b		6	42	245	9	27
10a		10	41	350	1.5	
10b		20	118	255	4.5	
12		20	18	207	.5	
17		49	43	290	1	10
25	10	30	21	400	1	
26a	4	16	17	140	3	
26b	3	12	10	90	1	

TABLE 1. (continued)

Lot Number	Depth of soil-ft.	Depth of weathering-ft.	Static water level-ft.	Well depth-ft.	Well yield in gal./min.	Percolation rate in min./inch
33	3	20	45	230	.5	20
34	6	18	43	185	12	57
35		3	89	300	1	10
37	3	5	15	290	1	20
40	10	25	34	170	3	10
44		21	55	305	1	20
50	1.5	43	200	397	1.5	10
57		2	114	320	2.5	23
58	2		65	170	3	14
64		14	75	125	9	35
67	9	45	165	400	35	20
73		5	177	410	1	20
83		14	80	305	5	10
86	4	18	130	170	7.5	5
92a		22	31	125	1	20
92b		32	54	300	3.5	10
93		6	6	110	6.5	13
F.H.			15	340	1	

TABLE 2. Measurements at individual home sites as determined from drillers well logs and percolation rates for individual lots obtained from county health department records of Boulder County.

Lot number	Depth of weathering-ft.	Static water level-ft.	Well depth-ft.	Well yield in gal./min.	Percolation rate in min./inch
			TALL TIMBERS		
3					10
4a	20		244	3	5
4b	30	30	170	1	10
5	15	30	135	4	20
6	20	30	100	3	5
8					6
9	15	50	150	4	15
10					30
11					5
14					8
15	15	70	185	3	5
17	10	50	195	1	
19	15	50	140	6	20
20	15	40	216	1	
21	15	30	90	4	5

TABLE 2. (continued)

Lot number	Depth of weathering-ft.	Static water level-ft.	Well depth-ft.	Well yield in gal./min.	Percolation rate in min./inch
22			186	2.5	48
23	20	75	150	1	10
24					10
25	20	90	190	5	15
27					20
28			150		
33	50	80	155	3	30
35					15
36					20
38	15	135	235	2	5
39					
40	17		290	1	10
42	20	50	130	2	
43a	10	30	70	5	5
43b	22	22	260	12	
45					21
48	20	50	155	4	10
50					8

TABLE 2. (continued)

Lot number	Depth of weathering-ft.	Static water level-ft.	Well depth-ft.	Well yield in gal./min.	Percolation rate in min./inch
58					5
60					10
64					13

TABLE 3. Measurements at individual home sites as determined from driller's well logs.

Name	Section	Date	Depth of weathering ft.	Depth of soil-ft.	Depth of alluvium-ft.	Static level-ft.	Well depth-ft.	Well yield in gpm
				GLEN HAVEN				
Adams	34	11-70	15	2	0	28	215	1
Letford	34	4-70	1	0	0	20	280	2.5
Rodgers	34	7-68	0	5	12	6	218	2.5
Roberts	34	1-60				10	14	2
Vanhorn	33	6-64	0	4	11	20	100	2
Mallow	32	2-63	0	0	50	12	50	1
Florio	28	7-63				100	140	1
Kephart	27	11-71	80	17	0	26	200	.5
Holt	27	5-70	17	8	0	10	150	50
Atkinson	27	11-66		8	30	12	30	4
Melcher	27	8-65	35	0	0	150	215	2
Boyle	27	8-61				10	17	10
Ernest	27	8-59				150	175	1
Himbarger	27	1-61				40	60	2
Hollbrook	25	8-67	0	18	0	20	155	1
Rhoadarmer	25	11-65	80	25	0	16	80	5
Sidwell	27	7-64					124	Dry

APPENDIX 3. Results of water quality tests.

TABLE 1. Results of water quality tests from Crescent Park in total coliform per 100 ml.

Sample no.		Sample date 7/10	7/17	8/14	9/27	11/10	TDS $CaCO_3$
1.	S	0	0	0	0	0	91
2.	S	0	0	0	0	0	82
3.	S	0	0	0	(pump inop.)	7	99
4.	S		0	0	0		101
5.	S	0	0	0	0	0	97
6.	S	0	0	0	0	0	83
7.	S			0	0	0	103
8.	S	0	0	0	0	0	65
9.	S	0	0	0	0	0	119
10.	S	0		0			117
11.	S	0	0	0	0	0	102
12.	V.P.I.	0	10	0	0	0	112
13.	S	0	0	0	0	0	136
14.	S	0	0	0	0	0	57
15.	S	0	0	0	0	0	74
16.	S			0	0	0	72
17.	S	0		0	0	0	52
18.	S	0	0	0	0	0	33
19.	V.P.I.	0	0	0	2	0	40
20.	S	0	0	0	0	0	43
21.	S	0	0	0	0	0	41
22.	S		0	0	0	0	78
23.	S			0			62
24.	S			0	0	0	59
25.	S	0	0	0	0	0	118
26.	S			0	0	0	157

TABLE 1. (continued)

Sample no.		Sample date					TDS
		7/10	7/17	8/14	9/27	11/10	$CaCO_3$
27.	V.P.I.	0	1	2	0	0	94
28.	S	0	0	0		0	98
29.	S	0	0	0	0	0	73
30.	S			0	0	0	57
31.	S			0	0	0	77
32.	S				0		42
33.	S		0				
34.	S				1	0	131
35.	S	0	0	0	0	0	159
36.	S			0	0	0	188
37.	S			0			

TABLE 2. Results of water quality tests from Tall Timbers in total coliform per 100 ml.

Sample no.		Sample date 7/13	7/21	8/17	8/30	10/3	12/12	TDS $CaCO_3$
1.	S	0	0	0			0	244
2.	S	0	0	0		0	0	153
3.	V.P.I.					0	90	217
4.	S			0		0	0	206
5.	P.I.		-	-	2	126	45	294
6.	S			0		0	0	233
7.	S			0		0		179
8.	S				0	0	0	243
9.	S	0	0	0		0	0	204
10.	S			0		0	0	200
11.	S			0		0	0	160
12.	V.P.I.	0	0	5	2	0	0	160
13.	P.I.		0	-	74	24	2	370
14.	S			0		1	0	240
15.	S	(Boulder city water)				0	0	
16.	P.I.	12		7	7	0	2	152
17.	S			0		0	0	152
18.	S			0		1	0	93
19.	S	0	1	0	0	1	0	101
20.	V.P.I.	0	0	0		0	43	158
21.	S		0	0		0	0	147
22.	S		0	0		0	0	171
23.	S			0		0	0	100
24.	V.P.I.		2	0	1		0	133
25.	S	0	0	0				96
26.	S	0	0	0		0	0	97
27.	S	0	0	1	1	0	0	102

TABLE 2. (continued)

Sample no.		Sample date						TDS
		7/13	7/21	8/17	8/30	10/3	12/12	$CaCO_3$
28.	P.I.		1	5	4			88
29.	S					0	1	126
30.	P.I.					136		313
31.	P.I.			2	-Cl	0	139	289
32.	S					0	0	542
33.	S	0	0	0		0	0	393
34.	S			0		0	0	277
35.	S		0	0		0	0	480
36.	S					0	0	398
37.	V.P.I.	0	0	4	0	3	0	321
38.	S	0	1	0	0	0	1	535
39.	S		0					145

TABLE 3. Results of water quality tests from Glen Haven in total coliform per 100 ml.

Sample number	Sample date								TDS
	7/7	7/14	7/28	8/16	8/19	8/30	10/10	10/15	$CaCO_3$
1. P.I.	0	76	34	300		62	16	20	27
2. V.P.I.	7	0	0	0		19	2	0	46
3. V.P.I.	2	0	26	40		0	0	0	126
4. V.P.I.	0	0	-	70		46	6	0	85
5. S					0				
6. V.P.I.					0		2	0	200
7. V.P.I.	0	0	0	105		0	0	0	205
8. S	0	0	0	0			0	0	310
9. S	0	0	0	0			0	0	480
10. S			0		0				
11. S	0	0	0		0			0	260
12. S					0		0	0	300
13. S	0								
14. S		0	0		0	0		1	65
15. S					0	0			
16. S					0				
17. S					0		0	0	165
18. P.I.					3	6			

TABLE 3. (continued)

Sample number	Sample date 7/7	7/14	7/28	8/16	8/19	8/30	10/10	10/15	TDS $CaCO_3$
19. P.I.					21		3	2	32
20. S					0				
21. V.P.I.	4	0	0	0					
22. S					0		0	0	34
23. P.I.					21				
24. S				0		0		0	38
25. S	0	0	0	1		0		0	38
26. P.I.	7	6	0	33		48		5	450
27. V.P.I.	0	0	9	0		0			
28. S					0		0	0	52
29. V.P.I.	0	0	0	20		0	0	2	133

TABLE 4. Results of stream water quality tests near Glen Haven, Colorado in total coliform per 100 ml.

SAMPLES FROM NORTH FORK (line indicates Glen Haven)

No.	TDS $CaCO_3$	Sample Date 7/6	7/7	7/13	7/26	8/30	10/10	12/13
1		53		23	4			
2					22			
3				3	2			2
4		90		21	4			3
5		63		30	4			3
6		88		25	2			0
Entering Glen Haven area of influence								
7	21	62		30	34	24	12	16
8	23	91		27	12	18	54	32
9		18		19	22	12	16	
10	23	96		50	4	42	14	17
11	25	41		15	12	42	56	30
Leaving Glen Haven area of influence								
12	23	33		25	36	14	54	26
13	23			2			40	
14	26	140		24	114	36	42	
15	28	180		11	40	64	40	

LOCATIONS OF SAMPLES - From confluence North Fork and West Creek

1. 7.0 miles above confluence, .5 miles from North Fork ranger station.
2. 5.8 miles above confluence, in Rocky Mtn. National Park.
3. 4.6 miles above confluence, above Deserted Village.
4. 4.5 miles above confluence, at Deserted Village.
5. 3.2 miles above confluence, above Trails End Ranch for boys.
6. 2.8 miles above confluence, below Trails End Ranch for boys.
7. 1.5 miles above confluence, just above Glen Haven influence.
8. 1.2 miles above confluence, in Glen Haven area.
9. .7 miles above confluence, in Glen Haven area.
10. .4 miles above confluence, above confluence of Fox Creek.
11. .2 miles above confluence, below confluence of Fox Creek.
12. .1 miles below confluence, just below Glen Haven area.
13. 1.2 miles below confluence, near picnic area.
14. 2.7 miles below confluence, below confluence of Miller Creek.
15. 7.5 miles below confluence, near fish hatchery above Drake.

TABLE 4. (continued)

No.	TDS $CaCO_3$	Sample Date 7/6	7/7	7/13	7/26	8/30	10/10	12/13
FOX CREEK								
16		55		23	8			
17	50	58		17	124	36	70	
18	50	47		28	24	110	74	
WEST CREEK								
19			54	47				
20			46	60				
21	21		70	TNTC	58	6	30	
22	24		65	55	138	18	46	
MILLER CREEK								
23	37			2	12	28	34	
24	42	16		7	82	104	62	
BIG THOMPSON RIVER								
25	35	TNTC		28	60	40	110	
26	35	TNTC		42	62	128	56	

LOCATION OF SAMPLES

16. 2.1 miles above confluence of North Fork and West Ck. above influence of Glen Haven.
17. 1.0 miles above confluence, at old Camp Bob Waite.
18. .4 miles above confluence, near confluence North Fork and Fox.
19. 4.7 miles above confluence, above "Dude Ranch" on Cow Creek.
20. 4.5 miles above confluence, below "Dude Ranch" on Cow Creek.
21. 3.0 miles above confluence, above Greely Camp Glen Haven.
22. .4 miles above confluence, above Glencrofter Store.
23. 3.7 miles above confluence Miller Ck. and North Fork above influence of new development.
24. .3 miles above confluence Miller Ck. and North Fork.
25. .3 miles above Drake, Colo. on Big Thompson River.
26. .3 miles below Drake, Colo. on Big Thompson River.