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A SYSTEM FOR GEOLOGIC EVALUATION OF POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES

by

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January 1975

ENVIRONMENTAL RESOURCES CENTER

Colorado State University
Fort Collins, Colorado

Completion Report Series
No. 59

A SYSTEM FOR GEOLOGIC EVALUATION OF POLLUTION POTENTIAL AT MOUNTAIN DWELLING SITES

PARTIAL
Completion Report

OWRR Project No. B-023-COLO

by

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submitted to

Office of Water Resources Research
U. S. Department of Interior
Washington, D. C. 20240

January, 1975

The work upon which this report is based was supported (in part) 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. 14-01-0001-1882

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ABSTRACT

Development of mountain homesites is accelerating in the Rocky Mountains of central Colorado. These homesites often require individual water wells and sewage disposal systems. Unfortunately, the widely used septic tank-leach field system generally is not suited for use in the mountainous terrain where soils are thin or missing. Although current federal regulations call for six feet or more of soil at the leach field site, many of the individual sewage disposal systems now in operation in the Rocky Mountain Region of Colorado fail to meet this requirement. Sewage effluent at these sites may directly enter bedrock fractures and travel large distances without being purified. As a consequence, contamination of streams, lakes, and ground water from these malfunctioning leach fields has become a problem of increasing magnitude.

Investigations of geologic, topographic,and hydrologic conditions at over 100 homesites in the Rocky Mountains of north-central Colorado have resulted in the development of objective criteria for evaluating pollution potential at mountain homesites. In addition, the results of these investigations indicate that contamination of water wells may be decreased significantly where geologic conditions are considered in the selection of sites for leach fields and wells. Although the results of these studies should be considered preliminary, they do tend to confirm that the orientation of jointing surfaces in the bedrock significantly affects the travel path of contaminants.

INTRODUCTION

The press of our growing population and the increasing affluence of our society have resulted in more and more people buying homesites in the scenic and relatively isolated mountainous areas of central Colorado. These mountain homesites often require individual wells and sewage disposal systems. Because many of the privately owned sewage disposal systems are poorly situated or improperly designed, wells and streams in the mountains are susceptible to contamination. Current federal resulations provide the principal constraints on design and construction of septic tank-leach field systems. These regulations are intended for use in regions where soil is six feet or more in thickness beneath the leach field area. Many of the individual sewage disposal systems now in operation in the Rocky Mountain region of Colorado are in technical violation of these federal regulations because of unsuitable soil conditions.

The mountain homesites are usually characterized by exposures of bare rock and areas of thin or discontinuous soil. This condition permits water and any contaminants which are present to directly enter fractures in the rocks. The filtering and purification of leach field waters can occur where soil or similar material receives the effluent, but the fractured crystalline rocks which underlie many mountainous areas do not effectively filter the percolating effluent. In addition, the rate and direction of contaminant movement through fractured rock may be difficult to identify. Therefore, the location of a leach field on a tract of land may be critical if contamination of well water is to be avoided. Current procedures, however, base selection of a leach field site largely on topographic and convenience factors. Where the subsurface consists of fractured crystalline rock, this is not a satisfactory practice. It should be clearly understood that neither acceptable "perc" rates nor the rule of thumb which calls for placement of a leach field downslope from a water well provide much insurance against contamination of the well water in mountainous terrain.

Investigations of over 100 homesites in the Rocky Mountains of north-central Colorado indicate that contamination of water wells may be decreased significantly where geologic conditions are considered in the selection of sites for leach fields and wells. Two separate but related field studies in Precambrian igneous and metamorphic terrain have provided data which illuminate the role of geologic conditions in the travel of ground water and contaminants in fractured media.

CASE STUDY #1: DISCRIMINATE FUNCTION ANALYSIS

In the first study (Freethey, 1969), 28 mountain homesites in north-central Colorado were selected for detailed analysis of variables thought to be related to pollution potential. See Figure 1 for general locations of study sites. The homesites were separated into two groups: the contaminated sites (Group 1) consist of homesites were contamination of the well water can

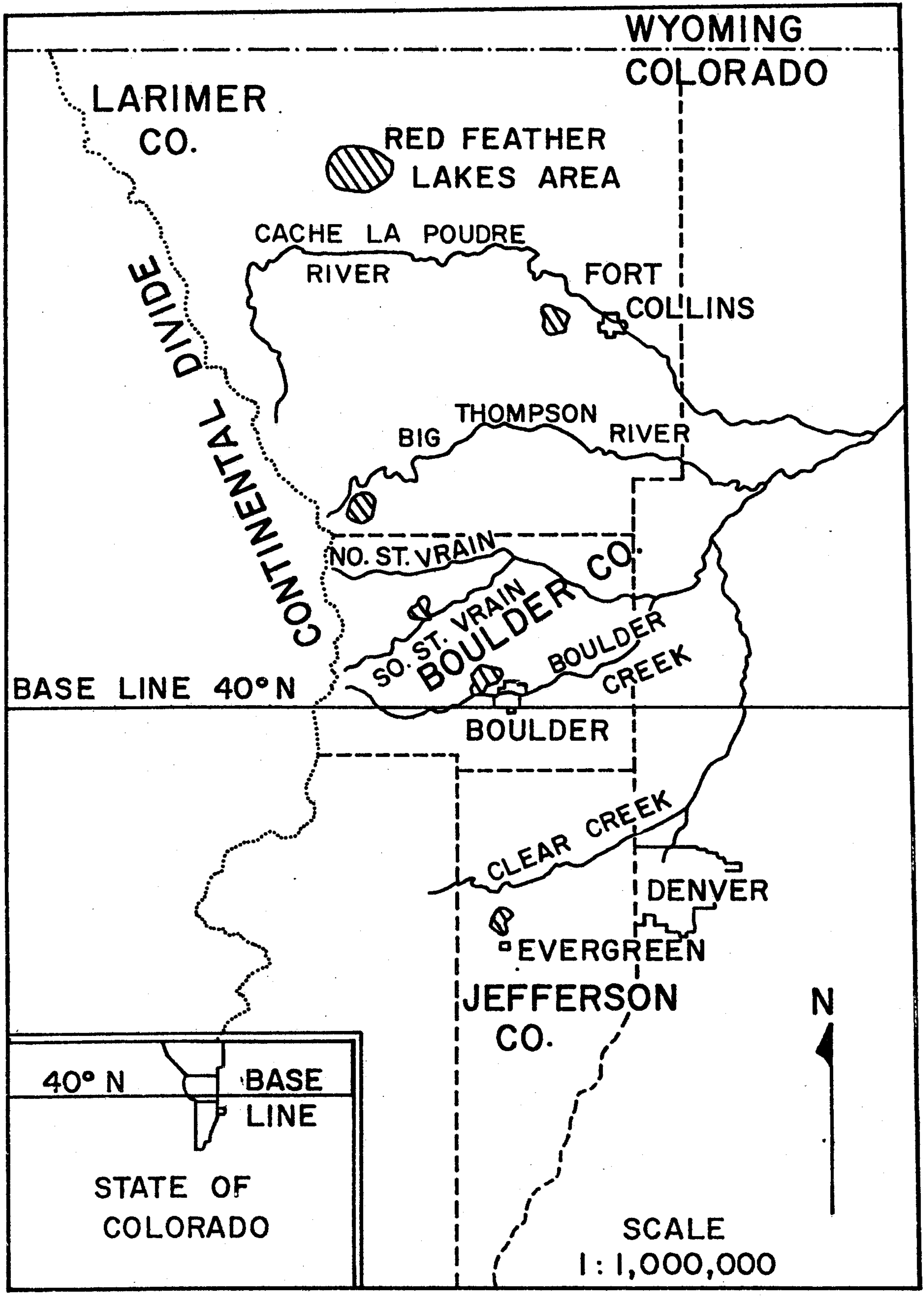


Figure 1. Location Map of Areas Studied. Areas are crosshatched.

be documented and a pollution source can be identified; the uncontaminated sites (Group II) consist of homesites where no contamination can be detected but where a pollution source is present. Placement of a particular homesite into either Group I or Group II was done on the basis of a water quality test for Escherichia coli bacteria. Seven of the twenty eight sites studied had wells which were contaminated with E. coli bacteria.

Selection of Variables

Quantitative measures of geologic, topographic, and hydrologic variables were collected at each homesite.

Geologic variables were devised to show the probable direction of effluent movement in relation to the position of the leach field and the well. Field data included measurements of the strike and dip of all major joint sets, foliation directions, and other fractures. These data were combined to obtain a "resultant" strike and dip which could be used as an approximation of the direction in which fluids would move through the unsaturated fractured media. To take into account the effects of spacing and width of fractures on permeability, a weighting procedure was devised by which fracture sets which appeared to be relatively impermeable would be assigned a ranking of one and fracture sets which appeared to have high permeability would be assigned a ranking of five. Fractures which appeared to have a moderate permeability were assigned rankings of 2, 3 or 4 depending on their apparent permeability. The "resultant" dip direction is obtained graphically using the rankings given to each measurement. Figure 2 shows an example of this procedure. The vector which represents the first measurement with a ranking of one is drawn only half as long as the vector for the second measurement, which has a ranking of two. After the resultant of one and two is obtained, vector number three is drawn, which because of its ranking of three, is three times as long as number one. The final resultant dip direction is obtained by drawing another parallelogram, the sides being measurement three and the resultant of measurements one and two. The dip angles of each of the original surfaces are then projected onto the vertical plane of the hypothetical resultant dip direction. These apparent dips can be quickly determined with the use of a special protractor (Lahee, 1952, p. 826). The apparent dips are then averaged according to their rankings, and a hypothetical resultant dip angle is obtained. This procedure is shown in part B of Figure 2.

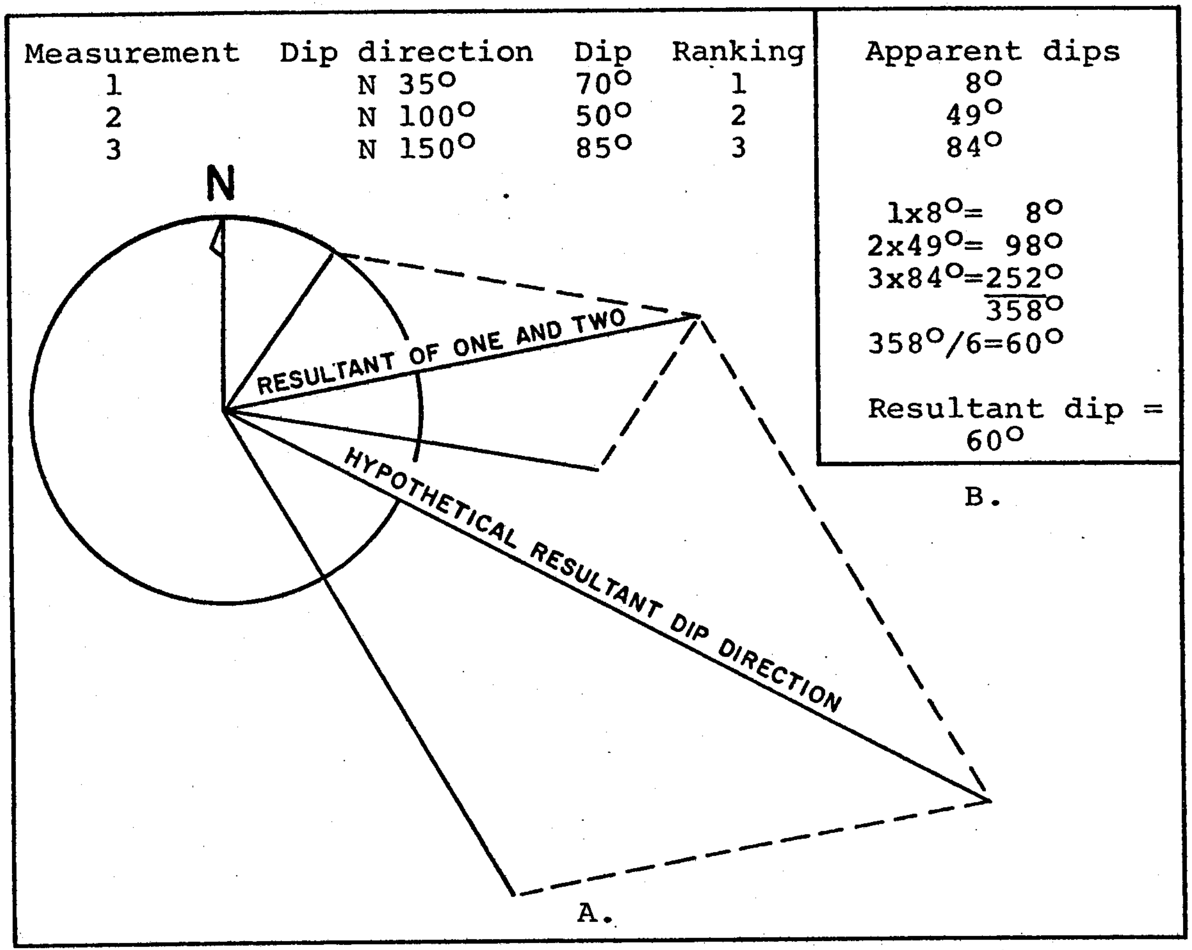
Geologic Variables

Three geologic variables used in this study involve angular relationships between the "resultant" strike and dip of fractures at each site and the orientation of a reference plane. The reference plane at each homesite is the vertical plane which passes through the leach field and the well. Figure 3 illustrates the geologic variables. A description of the variables follows:

Variable #1. Angle between the azimuths of the "resultant" dip and the leach field-well plane.

Variable #2. Acute angle between the azimuths of the "resultant" strike and the leach field-well plane.

Variable #3. Vertical angle between the line connecting the leach field with the water level in the well and the projection of the "resultant" dip onto the leach field-well plane.



Measurement	Dip direction	Dip	Ranking
1	N 35°	70°	1
2	N 100°	50°	2
3	N 150°	85°	3

Apparent dips
8°
49°
84°

1x8°= 8°
2x49°= 98°
3x84°=252°
358°
358°/6=60°

Resultant dip = 60°

Figure 2. Example for Calculation of the "Resultant" Strike and Dip of Fractures in Rocks. (After Freethey, 1969).

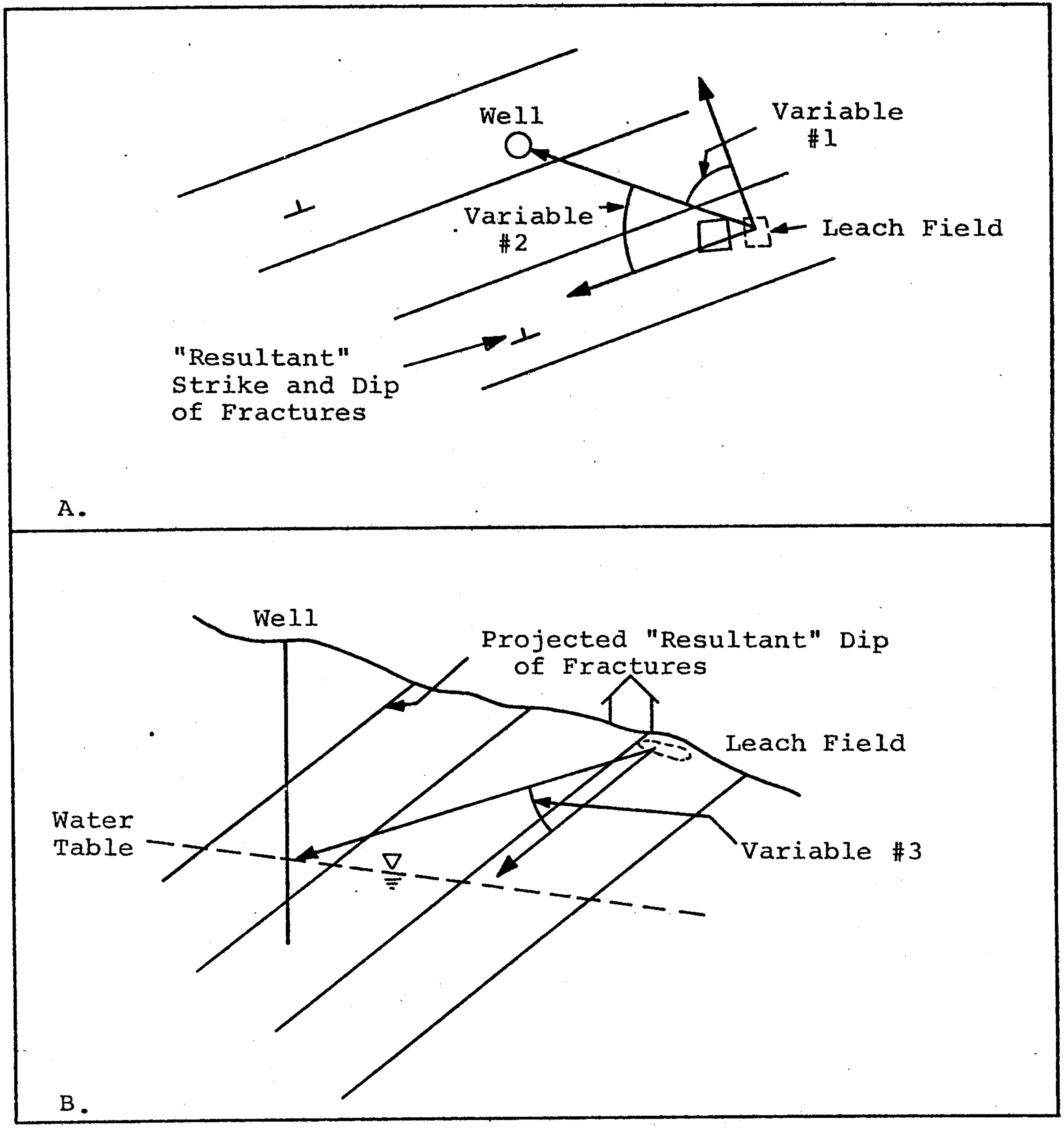


Figure 3. A. Diagram Illustrating Variables #1 and #2.
B. Diagram Illustrating Variable #3.

Variable #4. Degree of rock weathering. (Because weathered rocks may be effective in filtering and cleansing leach field effluent, some assessment of this variable was considered essential in evaluation of pollution potential at mountain homesites. A ranking procedure was devised. A rank of one represents relatively unweathered rocks, a rank of five represents a highly weathered rock mass.)

Hydrologic and Topographic Variables

The remaining variables used in this study were devised to represent those hydrologic and topographic conditions at the various homesites which are considered to be related to pollution potential. Figure 4 illustrates these variables. A description of the variables follows:

Variable #5. Angle between the azimuths of the water table gradient and the leach field-well plane. (In several cases the azimuth of the water table gradient was estimated from land surface topography.)

Variable #6. Depth to static water level in the well.

Variable #7. Vertical angle between the well head and the leach field.

Variable #8. Angle between the azimuths of the topographic gradient in the immediate vicinity of the leach field and the leach field-well plane.

Variable #9. Magnitude of the topographic gradient at the leach field as projected onto the leach field-well plane.

Variable #10. Horizontal distance between the well and the center of the leach field.

Statistical Analysis

A discriminant function analysis was done to determine if any of the ten variables used were related to or sensitive to the incidence of pollution. Briefly, the discriminant function analysis is a standard statistical technique which computes a

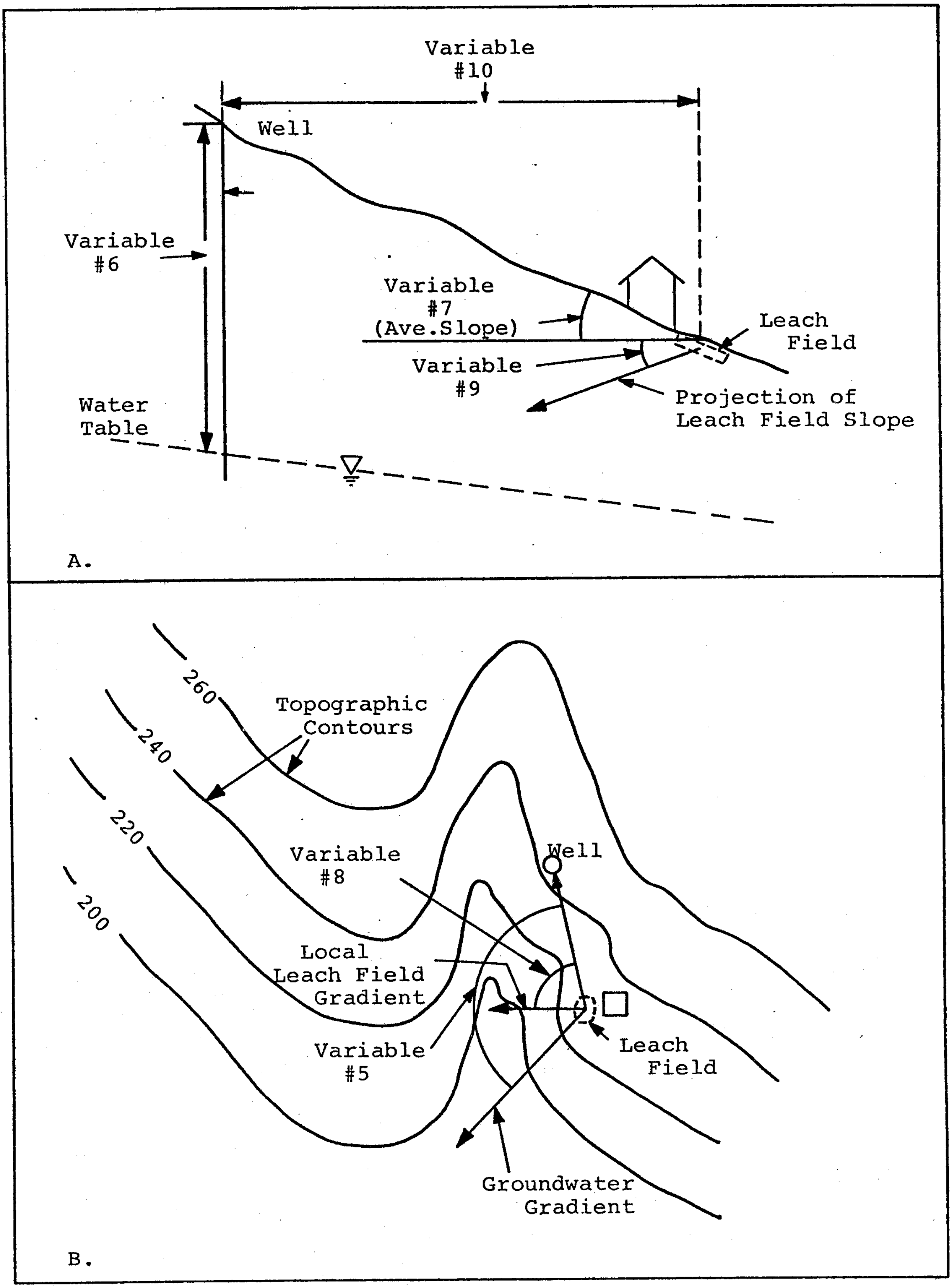


Figure 4. A. Diagram Illustrating Variables #6, #7, #9, and #10.
B. Diagram Illustrating Variables #5 and #8.

linear function of n variables measured on each individual of two groups. This linear function provides a criterion for discrimination between the groups. The function is computed so that the difference between the mean indices for the two groups divided by their pooled standard deviation should be as large as possible. Fisher (1946) discusses the computational steps and data requirements for the discriminant function analysis.

Results of Discriminant Function Analysis

The two most significant variables were variable #1 (angle between the azimuths of the "resultant" dip and the leach field-well plane) and variable #8 (angle between the azimuths of the topographic gradient at the leach field and the leach field-well plane). The significance of variable #1 apparently stems from the tendency of leach field effluent to follow the dip of fractures in the zone of aeration. The significance of variable #8 is possibly due to the tendency for near surface fluids to percolate laterally down slope in response to gravity and zonation of weathering. If lateral movement of effluent from the leach field has a component toward the well, pollution potential is increased.

Using only variables #1 and #8, a discriminant function significant at the 0.1% level was obtained. The values of the discriminant function for all 28 sites are given in Table 1. Values of the discriminant function are computed using the following formula:

$$D(f) = -.00196(V_1) - .0015(V_8)$$

Rank	Values for polluted group	Values for unpolluted group	Polluted site no.	Unpolluted site no.
1	-.09678		5	
2	-.12491		2	
3	-.14253		3	
4	-.18165		1	
5		-.22372		20
6		-.24201		18
7	-.24230		4	
8		-.28114		19
9		-.28536		21
10	-.29549		6	
11		-.30788		12
12		-.32189		13
13	-.35614		7	
14		-.36201		17
15		-.37507		10
16		-.37766		6
17		-.38321		3
18		-.39665		14
19		-.40115		15
20		-.40573		11
21		-.41615		8
22		-.41615		9
23		-.41714		2
24		-.42856		16
25		-.44093		7
26		-.46410		1
27		-.48433		4
28		-.51041		5

Table 1. Discriminant function values.

Where D(f) is the discriminant function, V_1 is the value for variable one, and V_8 is the value for variable eight. The discriminant function D(f) can be calculated for a site if estimates can be obtained for variables #1 and #8.

CASE STUDY #2: FLOW FIELD DIAGRAM METHOD

The second study (Millon, 1970) included 85 mountain homesites in the Red Feather Lakes Area, Larimer County, Colorado (see Figure 1). Sixty two percent of the wells tested at these homesites were found to be contaminated with E. coli bacteria. Data collected for 65 well sites established the position of each well relative to the nearest leach field. Data were also collected on the orientation of bedrock jointing surfaces and on water levels in wells so that ground water flow directions could be evaluated. Figure 5 shows contours drawn on water level elevations in wells. The study area was divided into 9 subareas in order to obtain a single generalized direction for the hydraulic gradient in each of the subareas. The generalized directions of the hydraulic gradient are indicated by the wide arrows in Figure 5. Orientations of major high angle joints in the Red Feather Lakes Area are summarized in Figure 6. The ground water flow pattern at any point in the area was assumed to be determined by the combined effects of the hydraulic gradient and the orientations of both major and minor jointing surfaces in the rock.

The data on well and leach field locations, joint orientations, and ground water flow potential were all combined by means of a specialized "flow field" diagram. See Figure 7. This diagram was developed to graphically illustrate how bedrock fracture orientations may affect transport of leach field effluent by ground water. A region of high pollution potential can be identified on the flow field diagram.

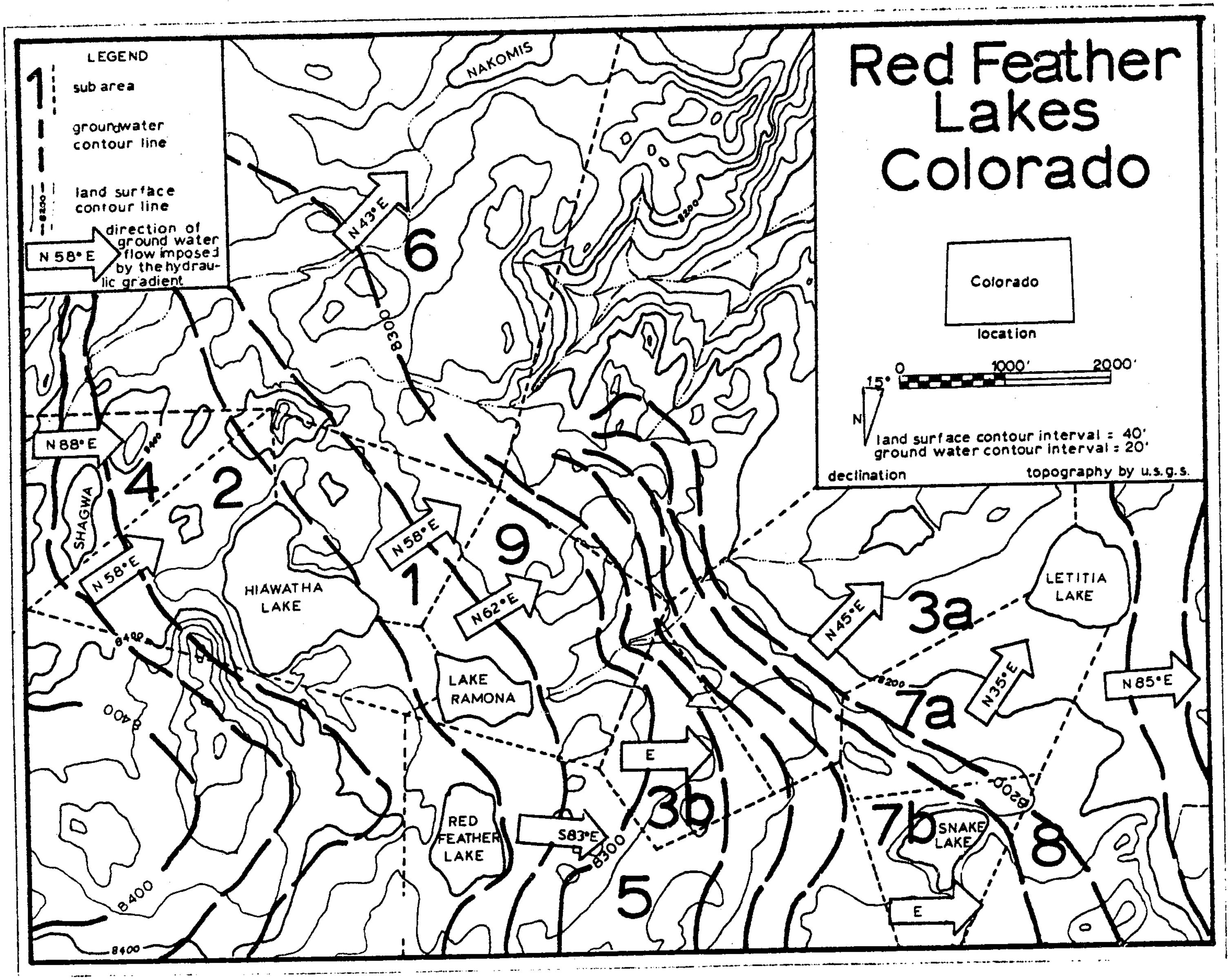


Figure 5. Map showing Subareas and Hydraulic Gradients for the Red Feather Lakes Area. (After Millon, 1970).

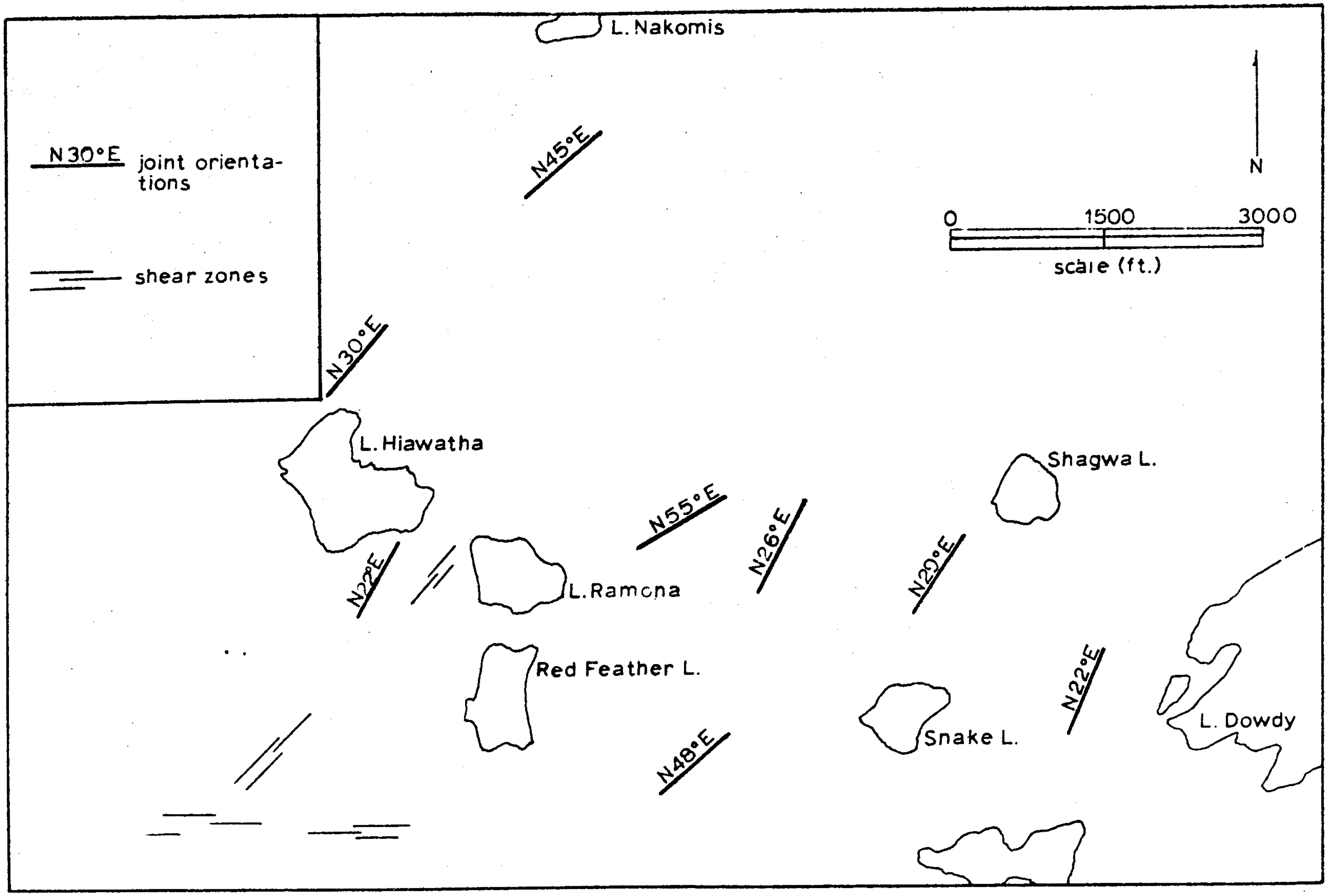
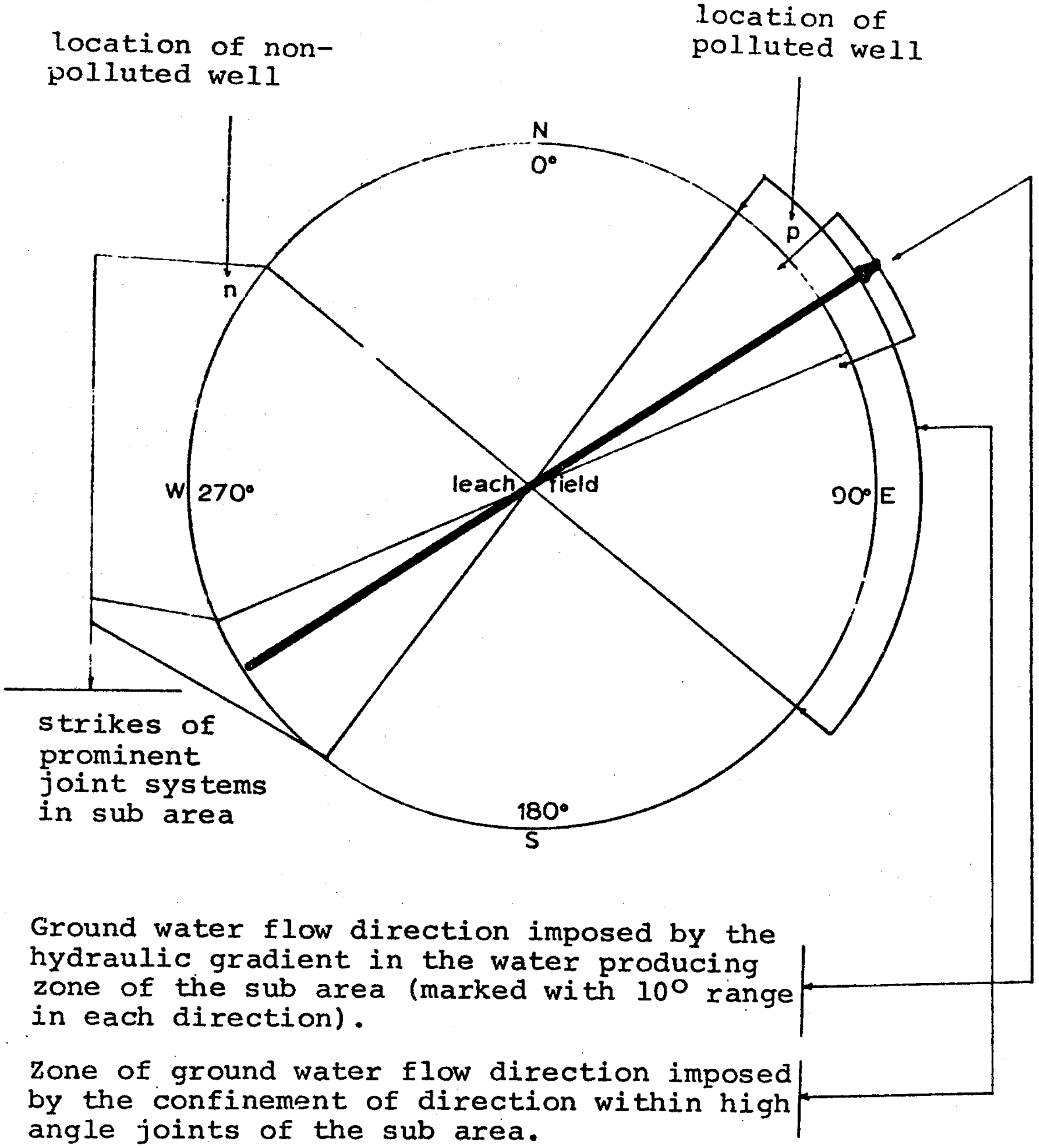


Figure 6. Map of study area showing joint and shear zone orientations.



Ground water flow direction imposed by the hydraulic gradient in the water producing zone of the sub area (marked with 10° range in each direction).

Zone of ground water flow direction imposed by the confinement of direction within high angle joints of the sub area.

Figure 7. Ground water flow direction chart showing locations of wells in relation to neighboring leach fields.

Results

The study showed that wells in the Red Feather Lakes area which, because of their position relative to nearby leach fields, plot on the flow field diagram within the region of high pollution potential have about four times the incidence of pollution as do wells which plot outside the region.

A normalized significance test employing Bernoulli data (i.e., the percentage of polluted wells in the flow field and the percentage of non-polluted wells in the flow field) was of the following form:

$$t = \frac{\hat{\pi}_p - \hat{\pi}_u}{\sqrt{\hat{\pi}_T(1-\hat{\pi}_T)\left[\frac{1}{N_1} + \frac{1}{N_2}\right]}} = 2.31$$

where

$$\hat{\pi}_p = \frac{\text{number of polluted wells in flow field}}{\text{total number of polluted wells}} = \frac{25}{45} = .555$$

$$\hat{\pi}_t = \frac{\text{total number of wells in flow field}}{\text{total number of wells}} = \frac{30}{65} = .462$$

$$\hat{\pi}_u = \frac{\text{total number of non-polluted wells in flow field}}{\text{total number of non-polluted wells}}$$

$$= \frac{5}{20} = .25$$

N_1 = number of non-polluted wells = 20

N_2 = number of polluted wells = 45.

The "t" value obtained by the above formula showed statistical significance at the one percent level.

CASE STUDIES #1 & 2: CONCLUSIONS

The analyses which have been described can be reliable only if geologic conditions are adequately represented. A hidden fault or igneous dike can invalidate a site evaluation based on the discriminant function or flow field criteria. Hence, these methods for evaluating pollution potential at mountain homesites should be considered reliable only in the statistical sense. Much additional data must be acquired before a generally applicable criterion for evaluation of pollution potential can be developed.

Although results of these two studies should be considered preliminary, they do tend to confirm that the orientation of jointing surfaces in the bedrock does affect the travel path of contaminants. Thus, evaluation of pollution potential at mountain homesites similar to those investigated in these studies must include detailed geologic analysis of bedrock underlying the thin soils.

Ultimately, correction of the pollution problem at mountain homesites can be achieved by the improvement of criteria used by local health department officials in approving applications for private sewage disposal systems. With an adequate sewage disposal system there is little need to worry about the potential for contamination of groundwater.

CASE STUDY #3: A REGIONAL ANALYSIS OF POLLUTION POTENTIAL

INTRODUCTION

The preceeding case studies have focused on both the need and the methods for determining pollution potential at individual homesites. The methods for analysis which have been presented are intended for use by the developer of mountain subdivisions, the eventual homeowners, and the local regulatory agency (usually the County Health Department) which must pass judgment on applications to install private sewage plants.

The following case study attempts to incorporate the knowledge gained through analysis of pollution potential at individual homesites into an evaluation of the larger scale pollution problems within a river basin. It is intended that the conclusions reported in this case study be of practical significance to land-use planners and decision makers at the county, regional, and state levels of concern.

OBJECTIVES

The objectives of this study are: 1) to evaluate the water quality problems within the South Platte River Basin related to home sewage disposal units, and 2) to make recommendations leading to the abatement of such problems.

EXTENT OF THE PROBLEM

Since 1968 over 1000 homesites within the mountainous portions of the South Platte River Basin have been studied to determine the causes and extent of water contamination due to faulty septic tank systems (Waltz, 1972; Biesecker, 1973). Approximately 20 percent of the wells tested were found to be contaminated with coliform bacteria. Although malfunctioning leach fields cannot be blamed for every occurrence of coliform bacteria in mountain ground water, it is suspected that the percentage of active leach fields which contaminate the mountain ground water is much higher than 20 percent; perhaps even higher than 50 percent. The rationale for this statement is based on the fact that most water wells associated with these pollution sources are located upslope (hydraulically) from the nearest leach field and consequently do not produce the contaminated water. Also, wells which are located down gradient from a pollution source may not produce contaminated water due to the patterns of ground water movement through the subsurface. As shown in Figure 1, the circulation of ground water through the fractured rock may follow a deep arcuate pattern which bypasses downslope wells and emerges directly as streamflow in the valley bottom. The circulation pattern of ground water flow lines depends in large part on the distribution of recharge and discharge areas for the flow and can usually be inferred from surface topography.

As implied in the preceeding statement, pollution of ground water by leach field effluent is undesireable not only because of the potential for contamination of nearby wells, but also because the contaminated ground water will probably discharge eventually into the nearest major stream. It is felt that contamination of the water resources within the South Platte Basin due to the malfunctioning leach field is a problem that is restricted pretty much to the mountainous portion of the basin. In the "plains" areas of the basin, leach fields are less numerous and their likelihood of failure is much less. This topic is discussed further in a later section of the report.

CAUSES OF THE PROBLEM

A catalog of the "causes" of the mountain septic tank problem includes items which are clearly interrelated but which merit individual presentation for purposes of better understanding the problem and for developing means to diminish it. Eight "causes" have been isolated for discussion; these are:

1. Many leach field sites are poorly situated.
2. Many leach field sites are improperly designed.
3. Soil at the leach field site often is too thin.

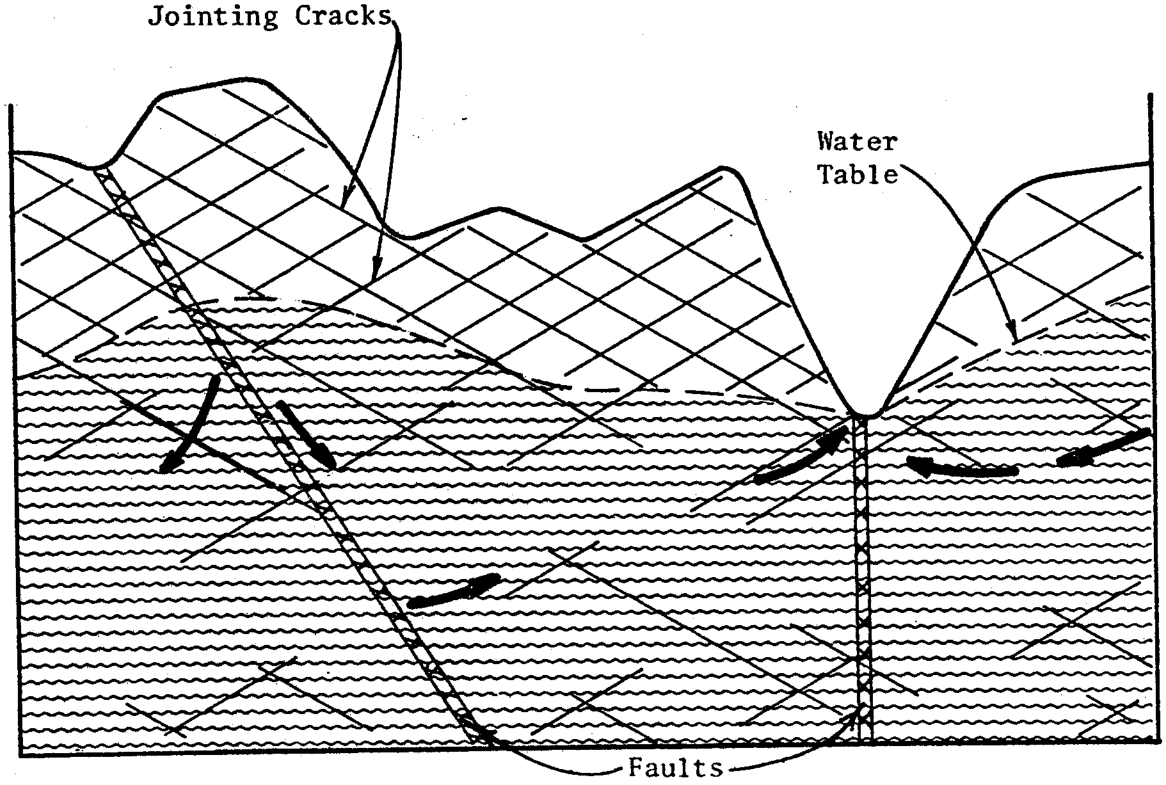


Figure 8. Hypothetical cross-section of mountainous terrain showing generalized flow pattern of groundwater toward a major drainage valley.

4. The underlying bedrock is generally not a good filter.
5. Soil may be hard to distinguish from weathered bedrock.
6. Flow directions for subsurface fluids are usually hard to predict.
7. Percolation test data are not adequate.
8. The "downslope" rule for leach fields is fallible.

1. Many leach field sites are poorly situated because they are underlain by a thin soil where bedrock conditions preclude effective filtration of the percolating sewage effluent. The problem is intensified if, in addition to inadequate filtering, the sewage effluent is permitted to discharge into the ground at a point where it can travel toward a nearby water well.

2. Many leach field sites are improperly designed as evidenced by their failure to function as intended. Two types of failures are commonly recognized for leach fields. First, is the failure to transmit the effluent rapidly enough to accomodate the peak flux of sewage (soil permeability is too low). This type of failure results in a backing up or surfacing of the effluent. With effluent at the surface, problems with odors and/or contamination of surface water are common. The second type of leach field failure is where the percolating sewage effluent is not adequatley purified before entering the ground water zone. This type of failure may be difficult to detect.

3. Soil at the leach field site is often too thin to permit adequate filtration of the sewage effluent. The U.S. Public Health Service Manual of Septic Tank practice (#526) indicates that 6 feet of soil should be present at the leach field site. This manual is inadequate in its discussion of "Suitability of Soil" (pg. 3) because it does not include a functional definition of soil in terms of its suitability as a filtering medium.

4. The underlying bedrock is generally not a good filter for sewage effluent. The bedrock often is sufficiently fractured and/or weathered to exhibit a satisfactory percolation rate, but

rarely does it purify the percolating effluent. Filtering effectiveness is determined primarily by the surface area of the medium with which the effluent comes in contact. The surface area/unit volume for fractured crystalline bedrock is generally considered to be several orders of magnitude less than that of a nonindurated sediment or soil. Even where chemical weathering (decomposition) of the bedrock is far advanced, fracture surfaces within the rock mass still tend to preferentially transmit fluids. The result is that chemically weathered rock is generally not an appreciably better filtering medium than fresh rock.

5. Soil may be difficult to distinguish from weathered bedrock. Soil scientists recognize the complexity of soil taxonomy and good support can be given to the argument that altered bedrock is a true soil. The definition of "soil", however, should depend on the use to which the soil is being put. As a medium for leaching fields, the soil must qualify for two distinct funtions; transmission <u>and filtering</u> of sewage effluent. The percolation test data may be adequate to support the conclusion that a soil is suitable as a transmission medium, but cannot be sufficient to establish suitability as a filter. The criteria which are now in general use for establishing soil suitability for leach field sites include percolation test data and soil thickness data as determined by excavatability. These criteria are inadequate. Weathered bedrock, like the surface soils, can generally be excavated or penetrated with an auger probe. This "softness" of the rock, however, is not an adequate indication of the filtering capacity of the rock.

6. Flow directions for subsurface fluids are usually hard to predict. Even if contamination of the ground water due to malfunctioning leach fields continues to occur, the "problem" of contaminated

well water and surface water could be reduced if accurate predictions were made about the flow path of the contaminated fluids after they leave the leach field site. Relative placement of leach fields and wells can be based on geologic data which relate to ground water flow characteristics (Waltz, 1972).

7. Percolation test data are not adequate. These tests are subject to various shortcomings. First, soil permeability usually varies both laterally and vertically: hence, the location and depth of the hole affect the percolation rate. Also, "perc" test data may not be reproducible due to operator technique or due to variables related to seasonal or weather effects. Winneberger (1970) provides a good discussion on the limitations of the "perc" test. Most important is the fact that the percolation data for the subsurface material give virtually no indication of the suitability of the soil as a filtering medium.

8. The "downslope" rule governing placement of leach fields is fallible. Depending on various geologic conditions, including the nature of the fracturing in the underlying rock, the depth to the water table, and the ground surface topography, adjustments in the relative positioning of wells and leach fields can be made to minimize contamination of well water. There is no assurance that a well is safe from contamination simply because it is located up slope from the leach field. The following pages contain a series of 4 figures which serve to illustrate how geologic variables can invalidate the common assumption that contaminated leach field effluent cannot move in a upslope direction.

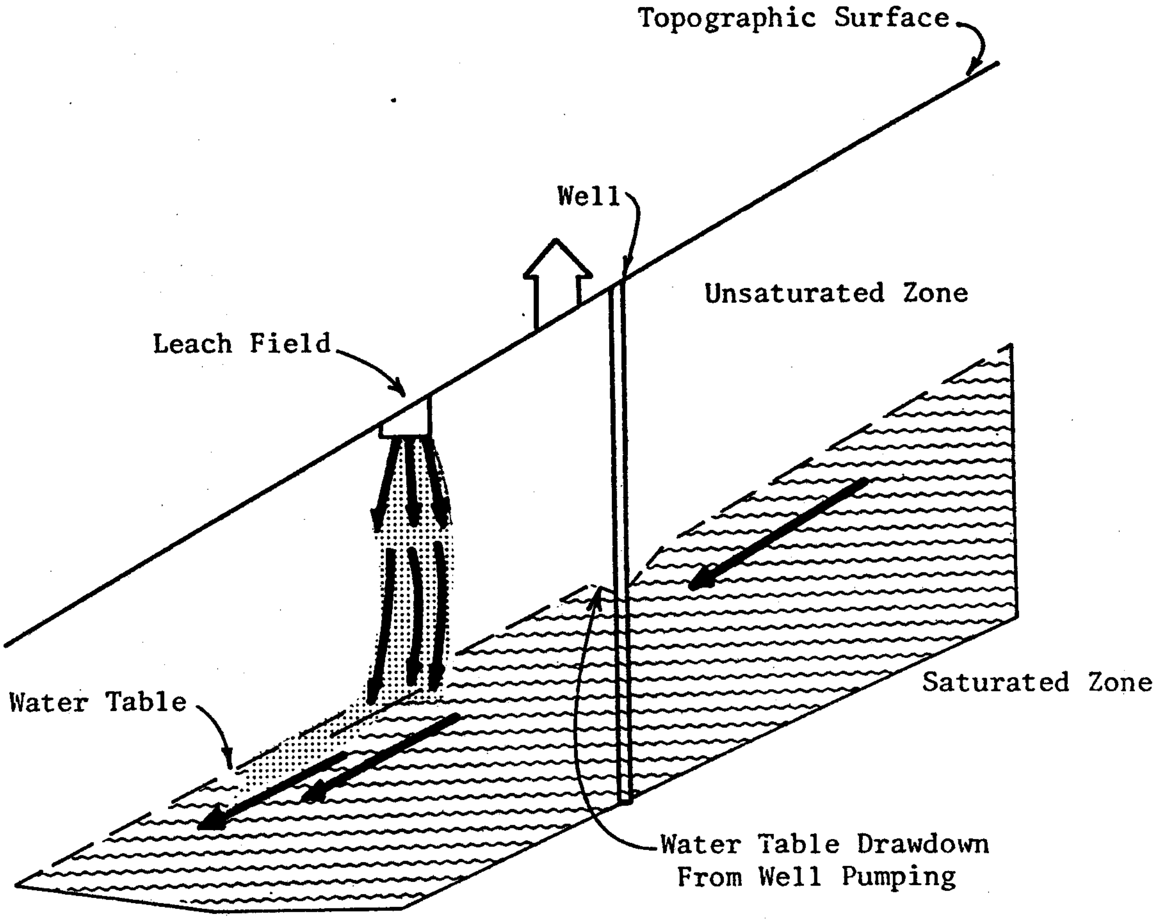


Figure 9. Ideal Situation: Well is placed upslope from leach field area. It is assumed that effluent from leach field will move generally in a downslope direction. This rule of thumb, however, has certain exceptions (see other illustrations).

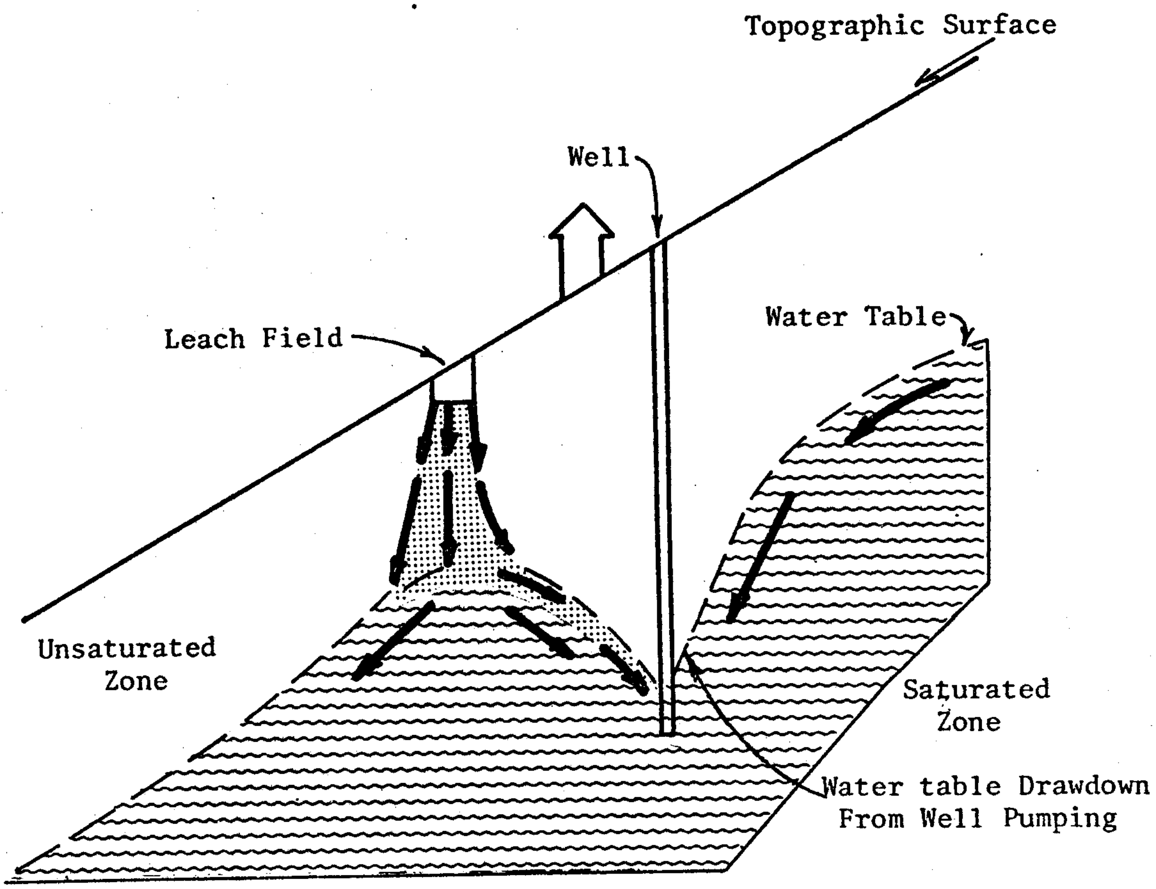


Figure 10. Exception 1: Rule of thumb fails because raw effluent reaches ground water supply within radius of influence of well. Large drawdowns are expectable for wells developed in fractured rocks. With well pumping, water drawdown near well causes local reversal in direction of flow of ground water.

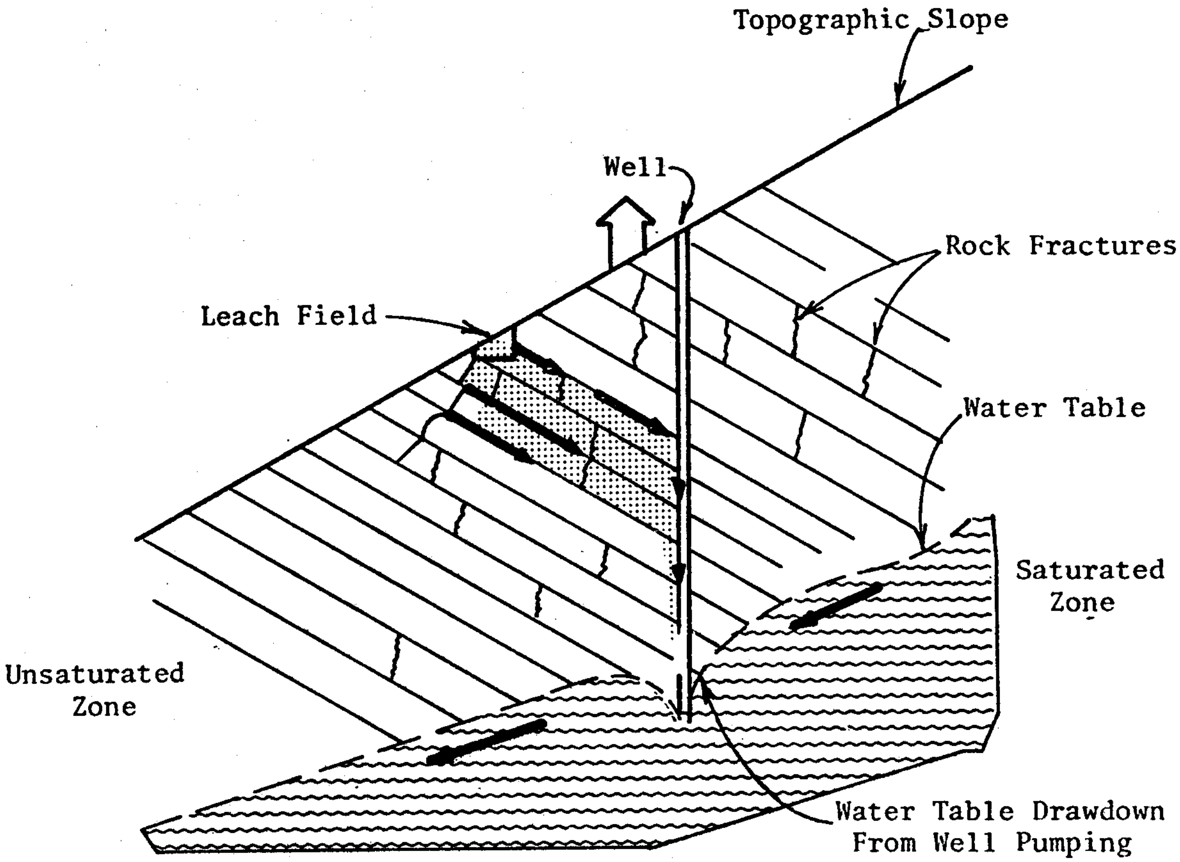


Figure 11. Exception II: Rule of thumb fails because rock fractures are inclined from leach field toward well. Effluent from leach field follows fractures above water table and enters well.

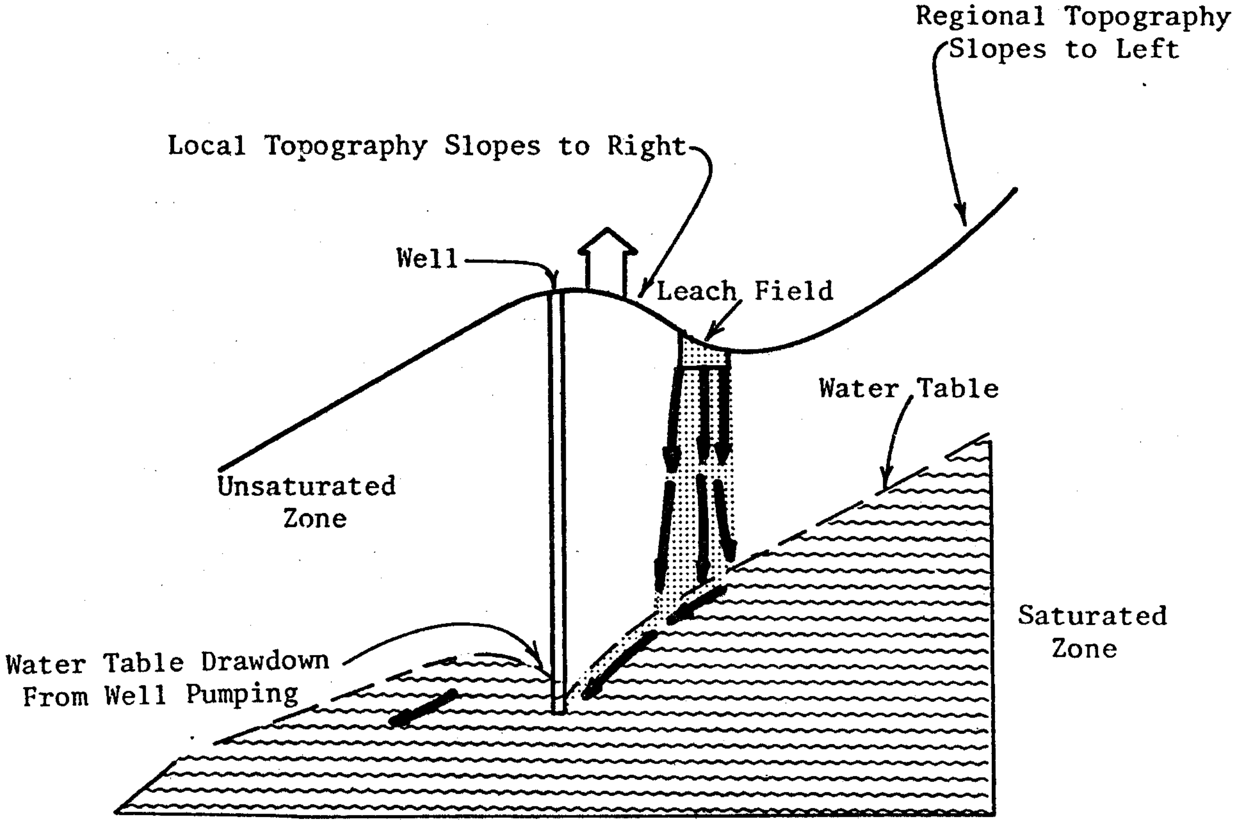


Figure 12. Exception III: Rule of thumb fails because local topographical slope changes. In this example, ground water flows in direction of slope of the regional topography. Thus, raw effluent can reach the ground water supply "upstream" from the well.

POLLUTION POTENTIAL IN THE PLAINS

The preceding discussions of the extent and causes of pollution in the South Platte Basin have focused on the mountainous portion of the basin. Contamination of water resulting from malfunctioning septic tank systems is not anticipated to become a problem in the plains (eastern) portion of the South Platte Basin. This conclusion is based on several factors. First, housing developments in the plains portion of the basin will generally be suited for community sewage collection and treatment systems. Subdivisions built in areas of relatively flat topography and where exposures of resistant bedrock are rare can usually be economically served by community sewer and water lines. Secondly, thick accumulations of sediment or soil are more likely to occur on the plains than in the mountains. These soils and sediments may or may not have acceptable percolation rates, but filtration of leach field effluent will generally be much more complete in sedimentary strata than in fractured crystalline rock.

Finally hydraulic gradients for ground water in the plains region will generally be lower and ground water flow rates much slower than those in the mountains. Bacterial contaminants from leach fields which reach the ground water, therefore, have more time to die off before emerging as stream flow or being picked up by water wells.

Exceptions to these comments on the plains can be observed where leach fields are constructed on highly permeable alluvial gravels within several hundred feet of active streams or drainages. Also, land areas underlain by thin soils and fractured sedimentary rocks can be found in some parts of the plains portion of the South Platte Basin. Where these areas are serviced by leach field sewage disposal systems, local contamination of the ground water is likely. It is doubtful, however, that large numbers of homes serviced by septic tank systems will be constructed on the flood plain gravels and shallow bedrock areas of the plains.

The pollution potential land classification map (Plate 3) which accompanies this report shows generalized soil characteristics which in turn reflect suitability for leach field installations. For interpretation of Plate 3, see the explanations starting on page 32 of this report.

MONITORING OF THE PROBLEM

In general, monitoring of the pollution problem can be either direct or indirect. Direct monitoring involves sampling of water from wells, springs and streams and testing of these samples for coliform bacteria. Considerable data on coliform tests for well water are presently available through the records departments of the various county health offices. These data, if collected and plotted, would provide a more complete delineation of problem areas within the basin. Additional testing of mountain water supplies is needed, however, if effective monitoring of the problem is to be achieved. Existing data are generally for wells for which a request for testing was made by the well owner. It is felt that a network of representative sampling locations equaling about 20 percent of the mountain domestic water supplies should be established and tests for coliform bacteria performed at least twice a year.

Indirect monitoring of the pollution problem involves application of theoretical or empirical models or formulae. For example, problem areas can be delineated by first observing where septic tank systems are in operation or proposed. These data are available through the various county health departments and county planning offices with the South Platte River Basin. The next step is to superimpose these locations on a map which shows land classes based on pollution potential, e.g., Plate 3 of this report. If time and funds were available to collect more data, a much more detailed map than Plate 3 could be developed. Where active or proposed septic tank sites plot on high pollution potential areas, "problem" points can be determined. Ideally, this indirect monitoring should be used in conjunction with direct sampling and testing procedures in order to achieve the optimum level of surveillance of the pollution problem.

It is plausible that monitoring of mountain water supplies should be financed in some areas by local home owner associations or water and sanitation districts. It would be to the benefit of these groups to establish "base line" data on their water quality now if they are to hold a tenable position later on in opposition to suspected sources of pollution.

ABATEMENT OF PROBLEM

For existing systems which utilize a leach field, abatement of a contamination problem can be achieved in a variety of ways. First, the water supply systems in the vicinity of the contaminated water can be modified to include a treatment process, perhaps chlorination. Second, the malfunctioning leach fields can be dug up and replaced with an engineered design which would minimize pollution potential. Thirdly, where residential densities and terrain permit, community sewerage systems could be substituted for the individual units. Of these options, I believe the second is best. Winneberger (1973) illustrates how modified versions of the conventional leach field design can be developed to suit most any terrain.

MINIMIZING FUTURE PROBLEMS

The first step in minimizing future problems is to firmly establish adequate criteria for the approval of leach field sites by the county sanitarians. Specifically, the criteria should include evidence of 6 feet or more of soil (not weathered bedrock) at the leach field site.

A second step in minimizing problems might involve application of field procedures for relative placement of wells and leach fields as described by Waltz, 1972. These procedures are presented on the assumption that the leach field will malfunction and their purpose, therefore, is merely to minimize the interconnection between the well and the leachfield.

Another method for minimizing future problems is to rely more heavily on engineered leach field systems which are designed to circumvent problems of thin or poor quality soil. I do not believe the solution to the problem of minimizing future contamination lies in legislating against private sewage disposal unit. If properly sited, designed, and constructed, individual sewage disposal units will remain the best option for domestic waste treatment in mountainous terrain.

Finally, steps should be taken at the state level to identify the entire front range and foothills area east of the Continental Divide as a "designated" area wherein special engineering and geologic studies must precede approval of private sewage disposal systems. A very small percentage of the mountainous areas east of the Continental Divide is clearly suited for private sewage disposal systems. For the areas which are suitable, the cost of proving this suitability would be quite small.

LAND CLASSIFICATION MAP

Plate 3 in this report is a map of the South Platte River Basin showing 5 classes of land. These classes are ranked according to their potential for pollution problems associated with septic tank systems. This map is intended for use as a regional planning tool, and should not be considered as a sufficient criterion for judging any specific leach field sites. The map is essentially a composite of three types of data: 1) bedrock type, 2) faulting, and 3) soil type.

Plate 1 of this report is a generalized soil map of the South Platte River Basin. The basic data for this map were compiled by

Engineering Consultants, Inc., Denver, Colorado. The soils map obtained from ECI contained 54 soil map units. For the purpose of developing a pollution potential land classification map, the 54 map units were regrouped into three classes of suitability for leach field systems: high, medium and low. The high suitability soils included all sandy and/or loamy soil classes; the medium suitability soils included silty soils and moderately thin lithic soils; the low suitability soils included clayey soil, thin lithic soils or rock outcrop areas, and high water table soils.

Because of the generalized nature of these soil classes, the inferences which have been drawn about pollution potential can at best be considered valid only in a statistical sense. This fact can be illustrated by pointing out that within a given soil class, e.g., high suitability, some land is almost certain to be present which is of moderate and/or low suitability.

Generalized bedrock geology is presented in Plate 2 of this report. Data for this map were taken from the Colorado State Geological Map at a scale of 1:500,000. Bedrock classes were also formulated on the basis of suitability for leach field sites. Sedimentary rocks were selected as being relatively more suitable; metamorphic rocks were considered to be of intermediate suitability, and igneous rocks were considered least suitable for septic tank systems.

These decisions were based in part on experience and in part on theoretical considerations. Sedimentary rocks are generally more porous and permeable than either igneous or metamorphic rocks, hence, a greater likelihood exists for filtering of sewage effluent which percolates into sedimentary rocks. Metamorphic rocks are generally less competent than

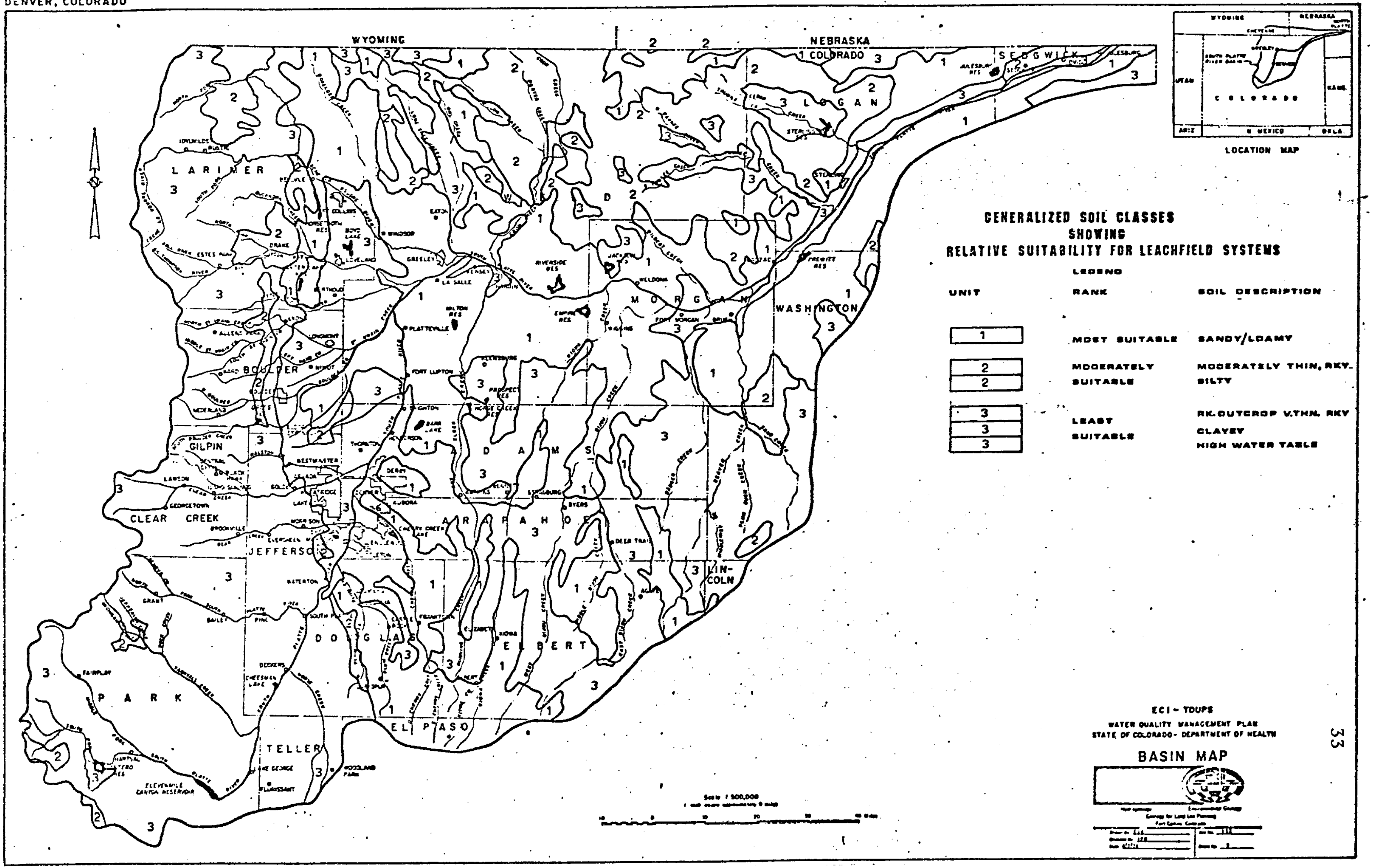


Plate 1. Generalized Soil Map of the South Platte River Basin.

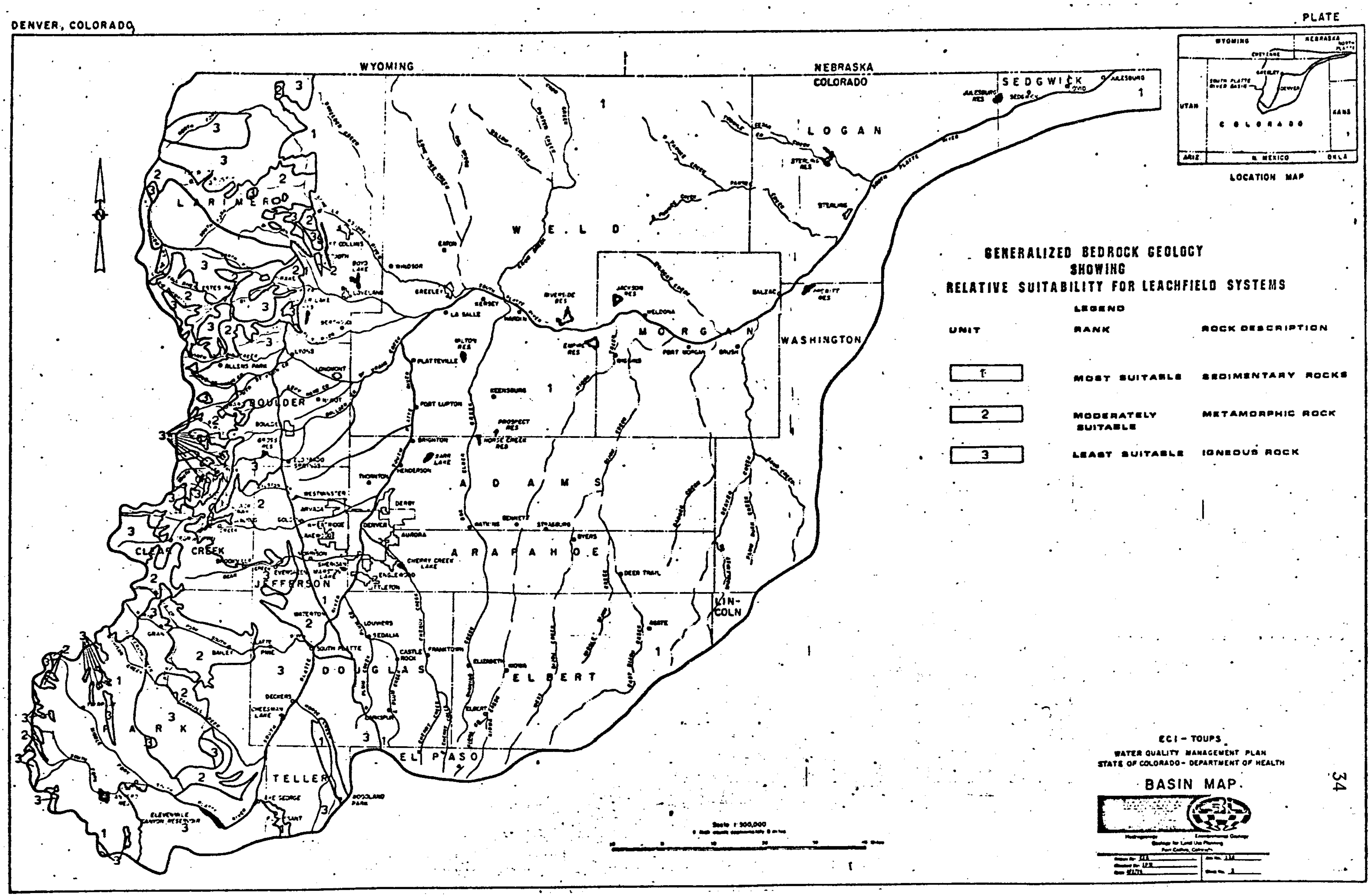


Plate 2. Generalized Bedrock Geology Map of the South Platte River Basin.

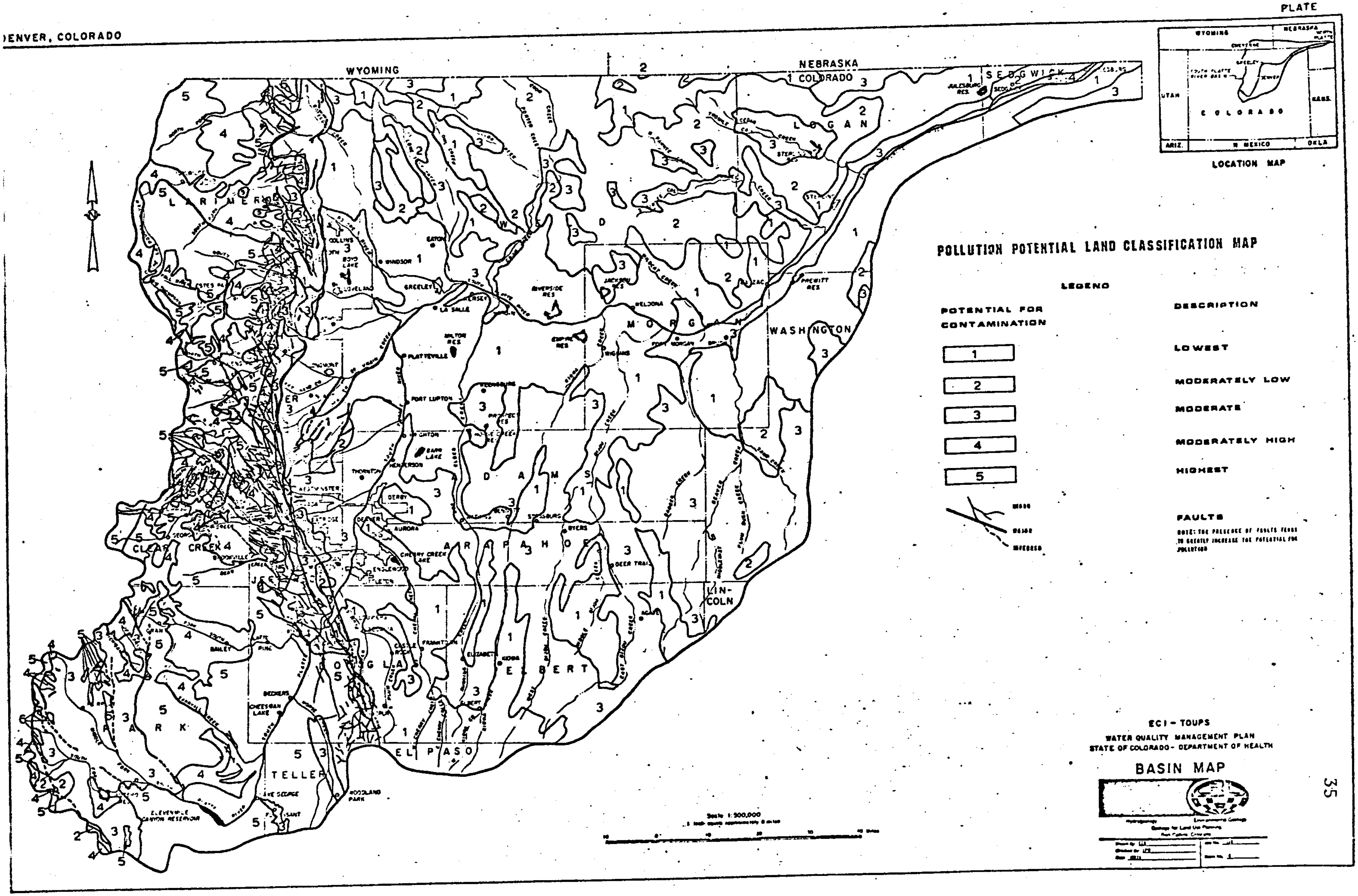


Plate 3. Pollution Potential Land Classification Map.

igneous rocks and consequently do not tend to have as many extensive open fractures at depth as do igneous rocks. Without deep continuous fractures, contaminants from leach fields cannot move freely.

Plate 3 was constructed by overlaying plates 1 and 2 and simply adding the soil and bedrock rankings to obtain a composite pollution potential ranking. The following table illustrates these combinations.

		Rocks		
	rank	sedimentary (1)	metamorphic (2)	igneous (3)
Sandy/loamy	(1)	2	3	4
lithic, mod thin silty	(2)	3	4	5
Rock outcrop/lithic clayey high watertable	(3)	4	5	6

Table 2: Method of combining soil and bedrock data to obtain pollution potential classes.

The pollution potential classes on Plate 3 which resulted from combining soil and bedrock data have been renumbered from 1 through 5 (rather than 2 through 6 as shown in the table).

Faulting also plays a significant role in the problem of pollution from septic tank systems. A fault is a major fracture within the earth's crust which may extend to great depths and be many miles long. The fractured rock contributes to pollution potential because contaminated fluids can move rapidly without being filtered within the fracture openings. Also, pollution problems are usually greater near fault zones because faults often provide the most reliable mountain water supplies. For purposes of land use planning, therefore, leach fields should never be sited near known faults unless special precautions against contamination are taken. The faults shown on Plate 3 are not the only faults present in the South Platte River Basin. In fact, these faults probably represent only half or less of the total number of significant faults in the Basin. The faults shown were copied out of a number of geologic reports, most of which were written in connection with the mining industry of the state. As a consequence, the good data on faults are generally restricted to those areas where mining potential was high. Therefore, it should be remembered that the absence of faults in some portions of Plate 3 does not mean necessarily that faulting is not present. Perhaps the main reason for indicating the presence of faults at all on Plate 3 has been to call attention to the fact that faults are common phenomena in the mountains and that they play a significant role in water supply and pollution potential for mountain residents.

Other geologic factors besides rock type and faulting can significantly affect the pollution potential of mountain land. A brief discussion of these factors is presented in the following section.

OTHER GEOLOGIC CONDITIONS WHICH AFFECT THE SUITABILITY OF LAND FOR USE OF SEPTIC TANK SYSTEMS

In the preceding section of this report, criteria were discussed which had been used to develop a pollution potential land classification map. The three major criteria presented were: soil type, bedrock type, and faulting. These three were selected from a long list of possible criteria for evaluating pollution potential. It is important to recognize the general nature of the data presented in Plates 1, 2, and 3, and that many exceptions are expected to occur within each of the mapped classes. Geologic conditions which contribute to these exceptions are many and varied, but usually can be recognized and evaluated in the field. A brief discussion of these geologic conditions follows.

ALLUVIAL DEPOSITS - Sediment deposited by streams is called alluvium. All stream valleys contain some alluvium. Where deposits are thick, suitable conditions for leach field sites may be present. Where the alluvium consists of coarse gravel deposits, however, filtration of percolating leach field effluent may be inadequate and result in contamination of the stream and/or nearby wells. A technique for estimating thickness of alluvium in mountain valleys is described by Pyle, 1969.

COLLUVIAL DEPOSITS - Sediment which accumulates in valley bottoms and on hillslopes due to erosion by gravity of weathered and weakened surficial materials is called colluvium. Colluvial deposits can occur in small patches almost anywhere and may prove to be adequate in thickness and permeability for use as leach field sites.

GLACIAL DEPOSITS - Sediment deposited directly by mountain glaciers is generally found only above elevations of about 8500 feet in the South Platte River Basin. Glacial deposits may be very thick and usually prove to be suitable media for leach fields. Glacial deposits also serve as important ground water reservoirs for mountain areas and should be used with caution as sewage disposal media.

IGNEOUS DIKES - Molten rock beneath the surface of the earth sometimes comes to the surface and is extruded as lava from a volcanic vent. In other cases, the molten rock cools slowly several tens of miles beneath the earth's surface. It is also common for molten rock material to be squeezed into existing rock fractures where it hardens to form igneous dikes or veins. These dikes serve to impound ground water and contaminants which are present. Normal ground water flow paths may be diverted if a dike is present, thus complicating the task of optimal placement of wells and leach fields.

OTHER FACTORS - Numerous other geologic conditions may locally influence the pollution potential of mountain land. Weathering of the rock and other alterations of rock properties such as secondary cementation or solution can control the occurrence and movement of ground water. Topographic slope and depth to ground water are two other geologic variables which affect the suitability of land for septic tank systems. Additional variables of this type are discussed by Waltz, 1972.

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APPENDIX

ABSTRACTS AND/OR REFERENCES TO REPORTS AND OTHER PRESENTATIONS SUPPORTED BY THIS PROJECT

Introduction

This project has generated a gratifying array of reports, publications, graduate theses, new research projects, seminars, presentations to professional groups, service clubs, and to local and state government entities, not to mention scores of requests from across the nation for copies of publications and considerable publicity in the news media.

The following abstracts and/or references to reports and other presentations supported by this project are included here as an attempt to document the impact of this project on the scientific community, the government, and the citizens.

THESES

Allen, M. J., 1972, Bacterial movement through fractured bedrock: Ph.D. dissertation, Colorado State University, Fort Collins, 111p. (See Abstract #1)

Beissel, D. R., 1971, Geophysical studies of fractured rock: M.S. thesis, Colorado State University, Fort Collins. (See Abstract #2)

Freethey, G. W., 1969, Hydrologic evaluation of pollution potential in mountain sites: M.S. thesis, Colorado State University, Fort Collins. (See Abstract #3)

Karl, Mark A., Prediction of flow in fractured rocks: M.S. thesis, Colorado State University, in progress

McCrumb, D. R., 1973, Geologic factors in the evaluation of water pollution potential at mountain dwelling sites: M.S. thesis, Colorado State University, Fort Collins. (See Abstract #4)

Millon, E. R., 1970, Water pollution, Red Feather Lakes Area, Colorado: M.S. thesis, Colorado State University, Fort Collins. (See Abstract #5)

Pyle, W. D., 1969, Estimation of alluvial fill thickness: M.S. thesis, Colorado State University, Fort Collins. (See Abstract #6)

OTHER REPORTS AND PUBLICATIONS

Allen, M. J. and Morrison, S. M., 1973, Bacterial movement through fractured bedrock: Ground Water, vol. 11, no. 2, p. 6-10. (See Abstract #1)

Allen, M. J. and Morrison, S. M., 1973, Bacterial movement through fractured bedrock: Environmental Resources Center, Colorado State University, Fort Collins, Completion Rept. Series #32. (See Abstract #1)

Burns, L. K., McCrumb, D. R., and Morrison, S. M., 1973, Geologic factors in the evaluation of water pollution potential at mountain dwelling sites: Completion Report Series No. 54, Environmental Resources Center, Colorado State University, Fort Collins. (See Abstract #4).

Waltz, J. P., 1972, Methods of geologic evaluation of pollution potential at mountain homesites: Ground Water, vol. 10, no. 1, p. 42-49.

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Ward, R. C. (editor), 1972, Proceedings workshop on home sewage disposal in Colorado: Information Series No. 4, Environmental Resources Center, Colorado State University, Fort Collins.

OTHER ORAL PRESENTATIONS

Waltz, J. P., 1971, Methods of evaluation of pollution potential at mountain homesites, presented at the National Groundwater Quality Symposium, Denver, Colorado, August.

Waltz, J. P., 1971, Groundwater pollution in the mountains, presented at a seminar for the Mountain Area Planning Council, Evergreen, Colorado.

Waltz, J. P., 1971, 1972, 1973, Testimony on mountain water pollution, presented before the Jefferson County, Colorado Board of Commissioners.

Waltz, J. P., 1971, Pollution of mountain water wells, presented at a meeting of the Association of Engineering Geologists, Denver Section.

Waltz, J. P., 1972, Testimony on groundwater contamination, delivered to Hearings before the Jefferson County, Colorado Board of Health.

Waltz, J. P., 1972, Testimony on Groundwater contamination delivered to the Boulder County, Colo. Board of Health.

Waltz, J. P., 1972, Pollution of groundwater at mountain homesites, presented at the Annual Meetings of the Colorado Environmental Health Association, Vail, Colo.

Waltz, J. P., 1973, Testimony on factors contributing to contamination of groundwater, before the Colorado Water Pollution Control Commission.

Waltz, J. P., 1973, Mountain Groundwater Resources, presented at the meetings of the 3rd Annual Rocky Mountain Ground Water Conference, Reno, Nevada.

Waltz, J. P., 1973, Environmental Geology in Mountain Land Development, a lecture presented at a short course for consulting geologists sponsored by the Assoc. of Engineering Geologists, Denver, Colo.

Waltz, J. P., 1974, Mountain Groundwater Problems, a presentation for the Water Committee of the Colorado State Legislature.

In addition to the specific presentations listed above, special programs on water pollution problems were presented to a number of service clubs, university seminars, and citizens groups.

ABSTRACT #1

BACTERIAL MOVEMENT THROUGH FRACTURED BEDROCK

The movement of bacteria-laden waters percolating through fractured bedrock was examined to determine whether effluent originating from conventional waste disposal systems could contaminate shallow ground water supplies. Inoculated waters were injected into holes and/or wells at two geologically different test sites to evaluate the extent of microbial filtration of leachfield effluent in or along bedrock fractures. Microbiological examination of tracer waters, samples both above and below the zone of saturation, were made.

Field studies showed that the direction and rate of movement of contaminated ground waters were controlled largely by the anisotropic nature of the geologic stratum, particularly by the orientation of major bedrock fracture sets. Injection waters, inoculated with *Bacillus stearothermophilis*, were found to be readily transported by the ground water gradient into a downslope well. At the Parvin Lake site the tracer bacterium traversed a horizontal distance of 94 ft. in 24-30 hr. Continued bacteriological analysis of the contaminated well found the tracer bacterium to be present for at least 6 days after inoculation of the upslope well.

In the zone of aeration, bacteria-laden effluent was found to percolate rapidly in or along bedrock fractures with inadequate filtration of the effluent occurring prior to entering potable ground water supplies. Studies conducted in a metamorphic rock formation demonstrated that while fecal-type bacteria decreased slightly during percolation through bedrock fractures, total bacterial densities were generally higher or unchanged following percolation.

Additional laboratory studies on 28 rock samples found microbial die-off rates as a result of toxicity due to the mineralogy of some common rock types to be negligible.

From the hydrogeological and microbiological data obtained at both test sites, it can be concluded that moderate percolation rates and minimal distances between water-wells and conventional waste disposal units are inadequate to protect potable ground water supplies from contamination in mountainous terrains. Thus, on most mountain building sites, it is essential that either

hydrogeologic data, such as bedrock fracture patterns, depth and movement of ground waters, seasonal fluctuations in ground water levels, be fully ascertained prior to installation of soil-absorption systems or alternate waste disposal methods should be selected.

ABSTRACT #2

GEOPHYSICAL STUDIES OF FRACTURED ROCK

The purpose of this study was to determine the orientation of buried joint systems in igneous and metamorphic rocks through the use of seismic refraction and electrical resistivity surveys.

A total of eight sites were studied. The sites were selected for their accessibility, the presence of adequate exposures for the measurement of fractures, and representation of various rock types.

The geophysical properties of the bedrock were sampled along N-S, E-W, NE-SW, and NW-SE lines at nearly every site. Data on joint orientations were collected at outcrops within and around the area of the geophysical surveys.

Multiple linear regression and correlation were used to determine if jointing affects the geophysical properties of the bedrock. The sample size was increased by dividing each site into sectors, the number of sectors equalling the number of geophysical profile lines at a site.

It was found that the joints present at the sites selected did not have a strong preferred orientation, thus the effect of the joints on the geophysical properties of the bedrock was not great enough to be determined above the effects of other geologic and hydrologic factors, such as variations in rock type, soil thickness, and moisture content.

ABSTRACT #3

HYDROGEOLOGIC EVALUATION OF POLLUTION POTENTIAL IN MOUNTAIN DWELLING SITES

Water supplies in mountainous terrain underlain by crystalline rocks are susceptible to contamination for several reasons. First, the sewage disposal systems at mountain dwelling sites are usually privately owned and may be unsafely situated with respect to the well site, and they may be poorly constructed. Second, contaminated surface water can usually percolate directly into the ground through fractures, joints, and foliation planes common in crystalline rock masses. In addition, the direction and rate of ground water movement through such rocks may be difficult to determine.

The purpose of this study was to classify mountainous terrain for use in evaluating pollution potential of dwelling sites found there. The study is limited to 28 dwelling sites in certain areas of Boulder, Larimer, and Jefferson Counties on the eastern slope of the Colorado Rockies.

The procedure used in this study included the measurement of certain geologic, hydrologic, and topographic characteristics of each site, and the formulation of ten environmental variables using these measurements. These variables from the 28 sites were segregated into two groups: group I included data from 7 of the 28 sites whose water supplies were found to contain a biological contaminant characteristic of a human source, and a source for this type of contamination is present in the form of a septic tank-leach field sewage disposal system; group II included data from the remaining 21 sites where water supplies were not contaminated, yet a potential source of contamination was present. To develop a classification system, data from both groups were used in a series of discriminant function analyses. The results of these analyses showed that, from the four most significant variables, three were geologic and one was topographic. Neither of the two hydrologic variables showed any significance in discriminating between a polluted site and an unpolluted site.

ABSTRACT #4

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.

ABSTRACT #5

WATER POLLUTION, RED FEATHER LAKES AREA, COLORADO

The purpose of this study was to determine the reasons for water pollution in areas where the water supply is derived by wells from ground water in fractured crystalline rock. The study, conducted in the Red Feather Lakes area of Colorado, consisted of determining: 1. The direction of ground water flow, 2. The relation of geologic structural control of ground water flow to pollution problems, 3. Other causes of pollution including: overloading of the ground water system with waste; the relative elevation of leach fields and wells; and type of well used.

A sampling program of wells in the area showed that 62 percent of the wells were polluted. From the ground water flow study it was found that a significant percent of these polluted wells were located down flow from leach fields. Thus, the geologic structural control of the direction of ground water flow is a possible cause of pollution.

Two possible situations which could cause overloading of the ground water system with effluent were found to exist: 1. Too many leach fields in a given area, and 2. Increase in the infiltration of bacteria with an increase in precipitation.

ABSTRACT #6

QUANTITATIVE GEOMORPHIC METHOD FOR ESTIMATION OF ALLUVIAL FILL THICKNESS IN MOUNTAIN VALLEYS

Interaction by several geomorphic agents of weathering and erosion develop and shape the land surface. The debris resulting from weathering and erosion often accumulates along valley bottoms to subsequently become alluvial deposits. Therefore, some topographic characteristics of mountain drainage basins should be correlative to depth of alluvial valley fill. An analysis of several topographic characteristics was made in order to develop a quantitative geomorphic method for estimation of alluvial fill depth in mountain valleys.

By quantifying valley wall-slope and valley-floor gradient as independent variables, a multiple linear regression analysis generated predicted values for the dependent variable of alluvial fill depth in 28 test cases with standard error estimates of about 5.94 feet. At a significance level of 99.9%, a 0.988 coefficient of determination was calculated in the analysis, indicating a definite statistical relationship between the independent and dependent variables.

Test data used in this study consisted of measurements of cross sections and topographic characteristics at existing or proposed dam sites. These data may not provide a representative sample of alluvial deposits; nevertheless, the range of lithologic, climatologic and vegetative conditions included in the analysis adds geologic significance to the study.

ABSTRACT #7

CONTAMINATION OF WELL WATER IN FRACTURED CRYSTALLINE ROCKS

Contamination of well water in fractured crystalline rocks is common where nearby septic tank-leach field systems are installed in thin residual soils. Data collected at mountain homesites in central Colorado indicate that home sewage effluent is not effectively purified by percolation through weathered crystalline rocks. Placement of water wells upslope from leach fields has been found to be an inadequate rule of thumb for preventing contamination. Also, the concept of a safe distance between leach fields and water supply sources has been found to be inappropriate in areas where thin soils overlie fractured crystalline rocks. To minimize pollution potential, placement of water wells in relation to sewage leach fields must involve analysis of topographic, geologic, and hydrologic variables. The geometry of fractures in crystalline rocks is the most important geologic variable. Anisotropy of permeability due to fracture systems persists even in highly decomposed rocks. Graphical and statistical analyses of field data show promise of providing improved objective criteria for planning private water and sewage disposal systems.