HYDROGEOLOGY AND WATER QUALITY STUDIES IN THE CACHE LA POUDRE BASIN, COLORADO

by

James P. Waltz

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ENVIRONMENTAL RESOURCES CENTER

Colorado State University
Fort Collins, Colorado

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HYDROGEOLOGY AND WATER QUALITY STUDIES IN THE CACHE LA POUDRE BASIN, COLORADO

Partial Completion Report
OWRR Project A-001-COLO
TITLE: GROUND WATER

June 30, 1969

by

James P. Waltz
Department of Geology
Colorado State University

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

Norman A. Evans, Director

HYDROGEOLOGY AND WATER QUALITY STUDIES IN THE CACHE LA POUDRE BASIN, LARIMER AND WELD COUNTIES, COLORADO

Abstract

The Cache la Poudre Basin, Larimer County, Colorado, provides an ideal laboratory for study and documentation of the causes and effects of water quality deterioration. It has been possible to correlate downstream changes in quality of surface water and groundwater to environmental factors including both natural and man-induced conditions.

Approximately half of the basin lies in mountainous terrain on the eastern slope of the Rocky Mountains in northern Colorado. Here, the effects of man's activities on the movement and quality of water have been relatively minor. Exceptions can be found in isolated areas where mountain home sites and camp grounds have become the source of biological contaminants because sanitary facilities are improperly situated and/or poorly constructed.

Within the mountain watersheds of the basin, harvesting of timber, mining, cattle ranching, and construction activities also produce changes in the patterns of movement and quality of surface and ground water.

The remaining half of the Cache la Poudre Basin lies in the relatively flat lands of the Colorado piedmont. Here, the quality of both surface and ground water are drastically changed due to the combined effects of changed geologic setting, agricultural practices, ranching, oil production, industry, and urbanization.

Several of the investigations summarized in this report have concentrated on problems of determining the properties of aquifers in the basin. Applications of geophysics, analog modelling techniques and studies of clay mineralogy have all played a role in defining the geologic framework in the basin and evaluating the effect of geology on the quality of ground water.

HYDROGEOLOGY AND WATER QUALITY STUDIES IN THE CACHE LA POUDRE BASIN, LARIMER AND WELD COUNTIES, COLORADO

(Final Report on OWRR Project A-001-Colorado, 1965-1969)

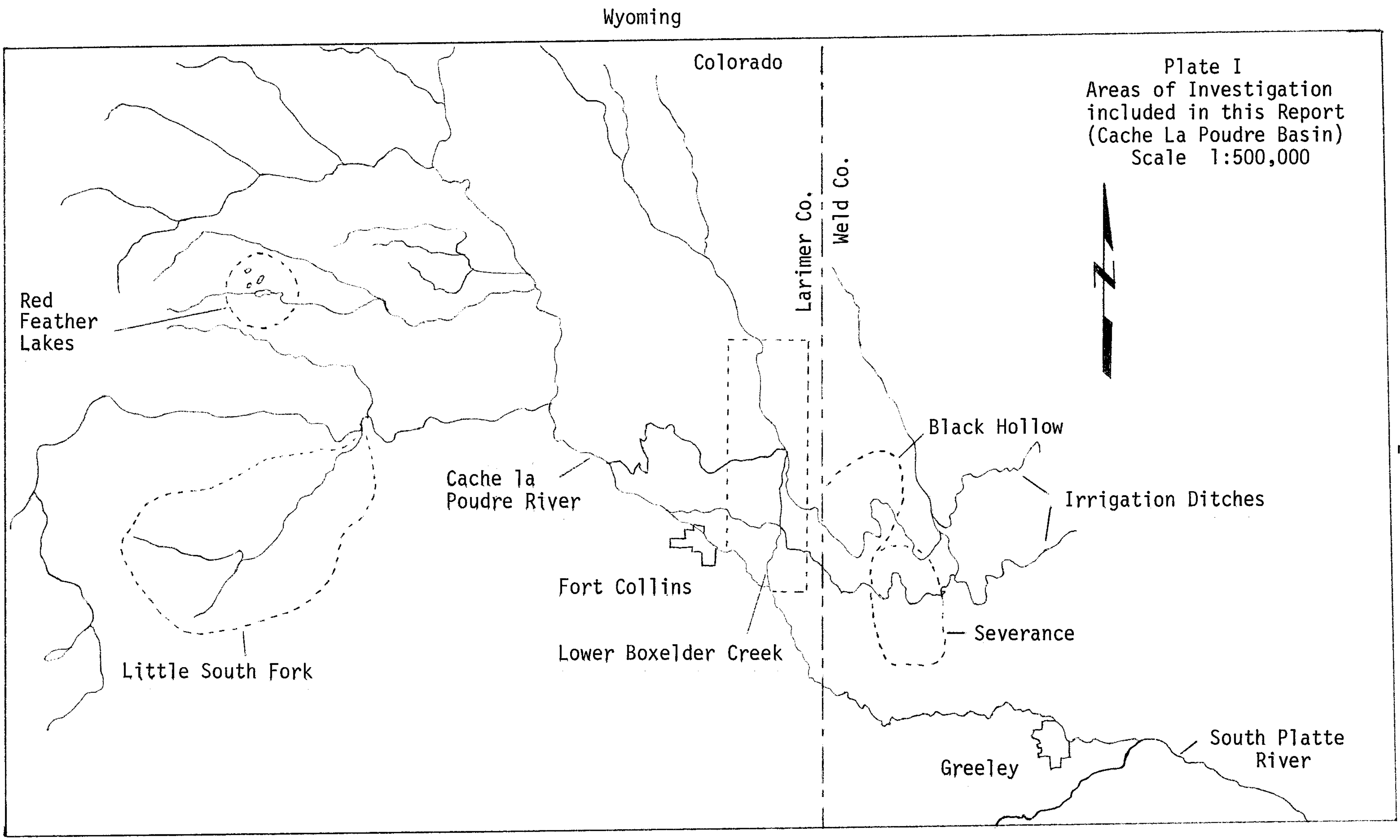
Principal Investigator: Dr. James P. Waltz
Department of Geology

Purpose of this Report

This report summarizes investigations related to the hydrogeology and groundwater quality of the Cache la Poudre Basin which have been carried out by the Department of Geology at Colorado State University over the period January 1, 1965 through June 30, 1969. Funding to the Department of Geology from the Office of Water Resources Research has resulted in the production of five M.S. theses and has partially supported work on several other M.S. theses and student reports in hydrogeology. Within the Department of Geology, newly funded projects in water resources research (B-022-Colo and B-023-Colo) owe their existence in large part to earlier support by the Office of Water Resources Research under Project A-001-Colorado.

INTRODUCTION

The Cache la Poudre Basin, Larimer County, Colorado, provides an ideal laboratory for study and documentation of the causes and effects of water quality deterioration. It has been possible to correlate downstream changes in quality of surface water and groundwater to environmental factors including both natural and man-induced conditions. (See Plate I.)


Wyoming
Colorado
Plate I
Areas of Investigation
included in this Report
(Cache La Poudre Basin)
Scale 1:500,000
Larimer Co.
Weld Co.
Red
Feather
Lakes
Black Hollow
Irrigation Ditches
Cache la
Poudre River
Fort Collins
Severance
Lower Boxelder Creek
Little South Fork
South Platte
River
Greeley

The Mountain Watersheds

Approximately half of the basin lies in mountainous terrain on the eastern slope of the Rocky Mountains in northern Colorado. Here, the effects of man's activities on the movement and quality of water have been relatively minor. Exceptions can be found in isolated areas where mountain home sites and camp grounds have become the source of biological contaminants because sanitary facilities are improperly situated and/or poorly constructed. Sites within the basin have been studied where sewage effluents reach the ground water and streams in a raw and dangerous form. Streams and ground waters in the mountains are particularly susceptible to contamination because soil in many areas is thin or absent and contaminated surface water can usually percolate directly into the ground via exposures of fractured or jointed rock. An additional problem is that the direction and rate of ground water motion in a fractured medium may be difficult to determine.

Within the mountain watersheds of the basin, harvesting of timber, mining, cattle ranching, and construction activities also produce changes in the patterns of movement and quality of surface and ground water. Grazing by cattle, removal of timber, and construction of roads, canals, tunnels and dams have imposed changes on the natural environment which are reflected by increased rates of erosion and deposition and consequent pollution of surface waters by sediment. The rates of infiltration and evapotranspiration are also affected and the balance of the hydrologic cycle becomes irreversibly altered.

As stated earlier, however, these changes in the mountain watersheds of the Cache la Poudre have produced relatively minor changes in the overall picture of water quality in the basin. In general, water produced by the mountain watersheds of the Cache la Poudre River is of good quality and very low in dissolved solid content.

The Piedmont Watersheds

The remaining half of the Cache la Poudre Basin lies in the relatively flat lands of the Colorado piedmont. Here, the quality of both surface and ground water are drastically changed due to the combined effects of changed geologic setting, agricultural practices, ranching, oil production, industry, and urbanization.

Mesozoic sediments underlie most of the piedmont portion of the Cache la Poudre Basin. These sediments locally contain soluble gypsiferous and calcareous deposits which contribute dissolved solids to ground water. Sink holes and solution channels have been observed in several localities within the basin. Some bedrock localities contain seams of lignite, coal, and iron-rich clays which also contribute to poor quality ground water.

Quality of ground water in the Lower Cache la Poudre Basin is affected most by agricultural practices. Canals, reservoirs and wells which have been constructed to distribute irrigation water have had a profound effect on the occurrence and circulation patterns of ground water. Applied irrigation waters wash soluble salts from the caliche zones in the soil. These salts, along with chemical fertilizers and pesticides may be flushed into ground water reservoirs or carried directly into streams. Reuse of groundwater through repeated irrigations inevitably produces increases in dissolved solids through evaporation losses and leaching processes.

Ranching activities affect water quality directly through contamination of natural water supplies by ensilage pits and feed lots. Furthermore, pasture land may be stripped dangerously low of the vegetation which protects the soil from excessive erosion.

Oil production and industrial processing constitute another facet of man's activities which contribute to deterioration of water quality in the Lower Cache la Poudre Basin. Brine pits, associated with oil wells in the basin, contribute contaminants to the ground water where seepage from the pits occurs. Meat processing plants, sugar refineries, and other industrial installations which use water in their functions inevitably contribute some contaminants or thermally polluted water into the streams and/or ground water of the basin.

Urban development brings concrete, asphalt, lawns, excavations, municipal dumps and other similar changes to the environment which in places radically alter the natural circulation of surface and ground water and produce deleterious effects on water quality.

Water Quality and the Geologic Framework

The quality of ground water changes in any basin with location and time. The movement of water through the geologic framework results in chemical interactions between the water and the earth materials through which it moves. Thus, the rate and natural patterns of circulation of ground water must be determined if the changes in quality of ground water are to be fully understood. For this reason, several of the investigations summarized in this report have concentrated on problems of determining the properties of aquifers in the basin. Applications of geophysics, analog modelling techniques and studies of clay mineralogy have all played a role in defining the geologic framework in the basin and evaluating the effect of geology on the quality of ground water.

The studies summarized in this report have perhaps resulted more in an increased awareness of the nature and scope of water quality problems in the basin than in solutions to these problems. The research done thus far, however, has generated new projects which will undoubtedly insure continued growth of our research activities and our accomplishments in the field of hydrogeology and its relation to ground water quality.

PART I: Investigations in Mountain Sub-watersheds of the Cache la Poudre Basin

Little South Poudre Watershed: Mercer (1966)

The Little South Poudre is one of the larger tributaries of the Cache la Poudre River, which drains approximately 105 square miles on the east flank of the Mummy Range in the north-central Colorado Front Range. (See Figure 1.)

The low total dissolved solids content, ranging from 28 to 77 ppm. of the surface water obtained from the region indicates the water is chemically of excellent quality. Starting with snow, the source of virtually all recharge in the region, mineral content increases on the average of 4 1/2 times as melt water comes in contact with soil and Precambrian crystallines, then triples again during penetration of the water into the ground-water system as it moves toward perennial springs.

Surface and ground water is predominantly of the bicarbonate-silica type with minor amounts of calcium, magnesium, sodium, potassium and other common chemical constituents.

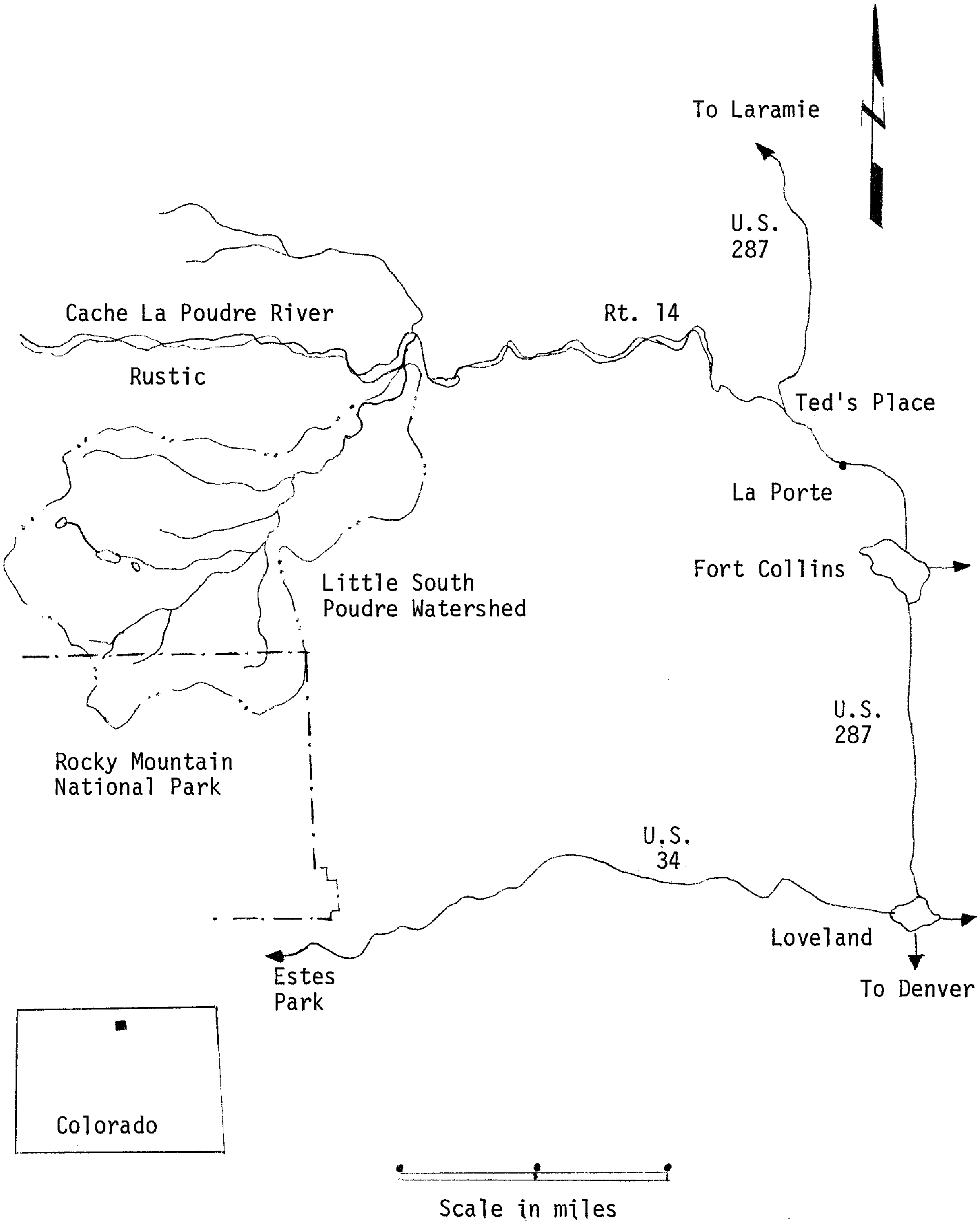


Figure 1. Location map of the Little South Poudre Watershed, Larimer County, Colorado.

As a water producing area, the Little South Poudre has a very high present and future value. Despite great differences in altitude, slope, vegetation, drainage area, runoff conditions, and geologic materials, the water released from summer snow pack remains remarkably uniform in composition and of excellent quality throughout the watershed, even during periods of peak flow. Supplementary to surface water, most ground water, even though somewhat higher in dissolved constituents, is also of excellent quality. Although values obtained represent water analysis data for only a short period of time, they should provide a basis for future detailed investigations of the watershed. The following conclusions have been drawn from this study:

1) Dissolved salts generally totaling less than 46 ppm and high relative percentages of bicarbonate and silica characterize the Little South Poudre surface water. Exceptions occur in Pendergrass and Fish Creek sub-watershed where values total as much as 75 ppm dissolved salts. The cause for these high values has been attributed to the increase of ground water contribution (higher in dissolved solids) to stream flow in these areas.

2) The bulk of water supplying the streams (with exceptions previously mentioned) is from summer snow melt with minor contributions from rainfall. Snow dissolved salt values (atmospheric source) are less than 10 ppm and are characterized by high percentages of bicarbonate and chloride.

3) High concentrations of total dissolved solids in ground water feeding the springs and streams (as much as four times greater than those for surface water) are probably due to acid pH values (6.9), and a longer contact-time of the water with rock materials.

4) Slightly alkaline conditions (pH around 7.4) when combined with low water temperatures (mean 9°C), tends to retard reaction of surface water low in total dissolved solids.

5) Local anomalous iron (ferrous) and copper concentrations are attributed to iron "fixing" bacteria and zones of copper mineralization, respectively.

6) From observations made by Mercer (1966), during peak runoff from snowmelt there appears to be little suspended sediment in the streams. During time periods immediately following a storm, maximum values from sampling reported by Kunkle (1966, oral communication) were approximately 219 ppm total suspended sediments in waters of the Little South Poudre in the Tom Bennett Campground area. The high concentration of suspended sediments in the Tom Bennett area was from erosion of the road cutbanks and road surfaces leading to the campground. Very little sediment was being contributed from runoff in other areas in the Little South Poudre watershed, thus indicating the relative stability of the watershed against natural erosion during storms.

7) Geologic studies indicate that the Fall Creek sub-watershed has undergone several episodes of glaciation and is underlain by biotite-quartzo-feldspathic gneiss, biotite schist, amphibolites and granite of Precambrian age. This lithology is thought to be representative of a major portion of the Little South Poudre watershed.

8) The Precambrian geologic history of the Fall Creek area involves several stages of regional metamorphism up to the highest rank of the almandine-amphibolite facies followed by stock-like intrusions of granite. Later, episodes of Pleistocene and Recent glaciation sculptured the sub-watershed.

9) Geologic-hydrologic investigation in the Fall Creek control area indicate that inorganic chemical constituents in the waters of the Little South Poudre were primarily derived from the bedrock.

10) Due to similar bedrock materials and weathering conditions, little variance in inorganic quality was found in waters draining glaciated areas as opposed to non-glaciated areas.

The results of this study should be useful to present and future water users in the Cache la Poudre basin. They may also be of interest to anyone concerned with the chemical character of water draining igneous and metamorphic terranes.

In addition, the information provides points of departure from which to evaluate changes in the chemical character of water as it moves from source areas progressively downstream into different geologic and hydrologic environments. The down-stream water, because of its development, use, and reuse by man, has received much more study than has source water. Thus, the sequence of chemical changes has commonly been studied in the middle and little attention has been given to source-water areas where processes and products can best be identified because water has a low concentration of dissolved solids and man's activities interfere little, if at all, with the natural regime.

<u>Beaver Creek Basin: Cerrillo (1967)</u>

Beaver Creek Basin is a glaciated basin of 20.5 square miles located in Larimer County, Colorado. (See Figure 2.) It is comprised of four large sub-basins: Hourglass, Comanche, Lake, Mummy, and Browns Lake, and two small sub-basins. Two existing surface reservoirs, Comanche and Hourglass (for which adjudicated water rights are

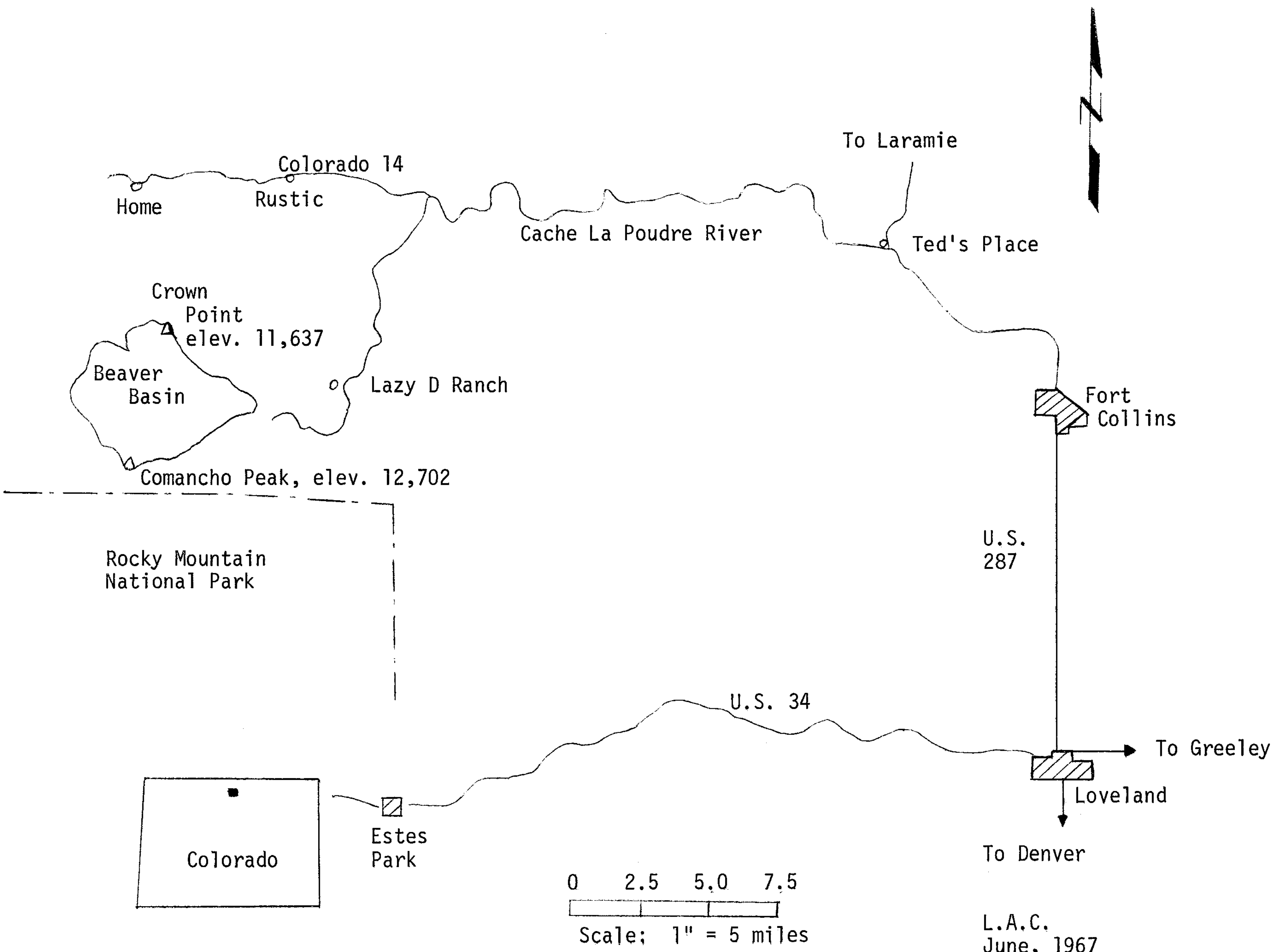


Figure 2: Location Map

approximately 2600 and 1600 acre feet respectively) are located within the basin.

The basement rocks in the basin consist of highly jointed granites, gneisses, and schists, overlain by glacial drift from four advances of Wisconsin glaciation (Bull Lake and Pinedale I, II, and III) and two advances of Recent age (Temple Lake and Gannett Peak). Extensive outwash deposits associated with the drift in the main basin, and especially in the vicinity of the reservoirs, are estimated to be 60 to 110 feet thick. These materials result in high infiltration rates to ground water within the main basin. Surface water losses to ground water in the sub-basins are due primarily to infiltration from small lakes, ponds, and swampy areas retained by moraines of the Pinedale III advance. Infiltration rates in the vicinity of the reservoirs range from 4 inches per hour to more than 23.4 inches per hour. Loss of surface water in this area is a direct result of high infiltration rates as well as indicated high permeability rates. Chemical and bacteriological quality of surface waters in the basin are excellent for domestic and irrigation needs.

The influence of glacial deposits on the hydrology of the basin makes a combined surface-ground water reservoir feasible.

Red Feather Lakes: (Millon, 1969; Freethey, 1969)

A pilot study has been completed on factors which affect water quality in the Red Feather Lakes Area, Larimer County, Colorado. (See Figure 3) Located within the watershed of the North Fork of the Cache la Poudre River, the Red Feather Lakes area has become a popular summer recreation site. Hundreds of cabins and homes have been constructed near the lakes and pollution of ground water from septic tank effluents has become a problem of considerable magnitude.

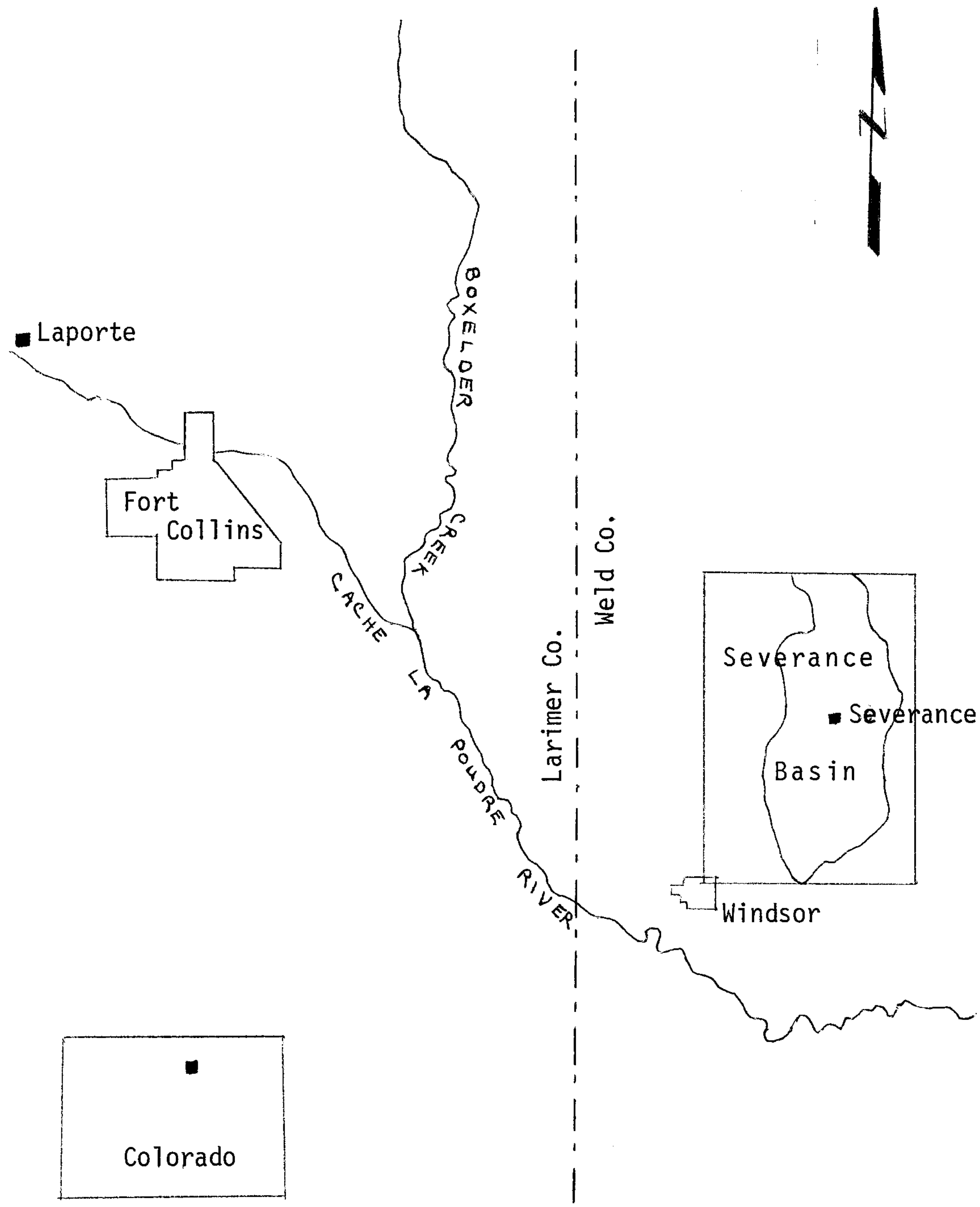


Figure 3. Location Map of the Severance Basin.

Bedrock in the area consists of the Precambrian Silver Plume Granite. The granite contains several major systems of joints and is highly weathered locally. The jointing and weathering patterns in the granite have produced an irregular topographic surface which has resulted in the presence of the Red Feather Lakes. Ground water levels are shallow and fluctuate with water levels in the lakes. The patterns of circulation of ground water appear to be closely controlled by local topography and geologic structure. Soils in the area are thin or absent, and consequently effluents from septic tanks in some places percolate directly into open joints and fractures in the granite. Travel of pollutants through these fractures may be rapid and filtering effects generally are inadequate to prevent contamination of water entering nearby wells.

The research to date in the Red Feather Lakes Area has been directed toward the development of a formula for evaluating pollution potential at home sites. To do this, a number of measurements were made of topographic, geologic, and hydrologic variables at selected study sites. These data were segregated into two groups: Group I contained information from sites where contamination has been documented and a source of pollution can be identified; Group II contained the same types of data from sites where no contamination can be detected, but where a pollution source is present. To develop a formula for evaluating pollution potential at these home sites, data from both Group I and Group II sites have been used in a series of discriminant function analyses. The results of these analyses are as follows:

1. A discriminant function was developed which correctly classified 16 of the 18 sites studied. One polluted site was incorrectly classed as

unpolluted; and one unpolluted site was incorrectly classed as polluted. The statistical significance of this discriminant function as indicated by the "F" statistic was 95%.

2. The environmental variables used in the analyses which proved to be sensitive indicators of pollution potential, listed in order of their importance, are as follows:

A. Topographic slope between well and leach field

B. Relation of geologic structure to well and leach field

C. Microtopography around the leach field

D. Horizontal distance between the well and leach field

We hope that ultimately this project will result in the development of improved criteria for the location and construction of wells and leach fields so that pollution potential is minimized at mountain dwelling sites. Additional research on this problem has been funded by the Office of Water Resources Research under project number B-023-Colorado.

PART II: Investigations in Piedmont Sub-watersheds of the Cache la Poudre Basin

<u>Severance Basin</u>: (<u>McComas, 1966</u>.)

The Severance Basin is located in the drainage of the lower Cache la Poudre River approximately midway between Fort Collins and Greeley. (See Figure 3) Agriculture in the area is dependent on irrigation to supplement the low mean annual precipitation of 11 inches. Irrigation water is supplied by the Eaton Canal and by ground-water wells.

The principal aquifer consists of alluvial deposits which overlie the Cretaceous Fox Hills Sandstone and occupy the small valleys of the basin. Ground water is also present in small quantity in terrace gravels, sand dunes, and colluvial deposits which mantle the uplands. (See Plate I.)

The ground water has an average total salt concentration of 2060 parts per million and is generally unacceptable for most domestic use. Salinity of ground water is highest where the ground water is associated with shallow colluvium and where the ground water is near point source contaminants. The total salt concentration of the ground water increases southward in the basin.

Contamination of the ground water in the Severance Basin is effected by the leaching of soluble salt from the soils and soil parent material and by wastes from brine pits, ensilage pits, and cattle feedlots. The soluble salt in the soil results from the combined effect of chemical breakdown of geologic materials, evapo-transpiration of applied irrigation water, and agricultural soil additives. Data on water quality in the Severance Basin are tabulated in Tables 1 and 2. Conclusions and recommendations for further research in the Severance Basin are as follows:

1. The major source of soluble salts in the soil is believed to be the geologic materials. This is suggested by thick layers of calcium carbonate developed in the Terry and Larimer soils derived from bedrock and old alluvium. Ground water in the zone of these soils is generally the poorest in the basin and has high concentrations of calcium, magnesium, sodium, and sulfate. These elements appear to be derived from the bedrock and old alluvium.

2. The contribution of salts by imported irrigation water cannot be thoroughly investigated due to a lack of pre-irrigation water-quality records. In the opinion of the investigator (McComas), the

TABLE I--Analysis of water from wells in the Severance Basin.

Results in parts per million, unless otherwise indicated. Geologic source; Q_c, colluvium; Q_a, alluvium; Q_t, terrace; Q_{sd}, sand dune.

Well Number	Well Location	Depth to Water Ft.	Date Sampled	Geologic Source	pH	Specific Conductance mmhos x 10^6	Cal-cium	Magne-sium	So-dium	Potas-sium	Car-bonate	Bicar-bonate	Chlo-ride	Sul-fate	Ni-trate	Total Dissolv Solids
WW 1	B7 67 24cbb		8-02-65	Q_c	7.8	1855	150.3	131.3	135.0	14.0	0.0	566.1	56.0	603.3	11.7	1369
WW 1			5-15-66		7.6	2240	122.5	152.5	125.0	15.8	0.0	546.6	60.0	717.0	4.2	2240
WW 2	B7 67 23dda	16.4	8-02-65	Q_t	7.7	1701	146.3	127.7	125.0	4.5	0.0	673.4	58.0	436.2	5.0	1701
WW 3	B7 67 23dbd	5.9	8-02-65	Q_t	7.8	1681	142.3	114.3	125.0	4.5	0.0	673.4	72.0	434.5	5.7	1168
WW 6	B7 67 26aca		8-02-65	Q_a	7.8	1902	170.3	149.6	125.0	1.5	0.0	424.6	26.0	829.6	7.0	1652
WW 6			5-15-66		8.2	2290	196.4	180.0	121.3	2.5	43.2	434.3	32.0	937.6	1.9	1756
WW 7	B7 67 26bdc	5.0	8-02-65	Q_t	8.2	2453	162.3	181.2	235.0	2.5	19.2	346.5	68.0	1153.0	1.1	2280
WW 7		10.5	5-15-66		8.1	1828	145.0	142.5	155.0	3.5	33.6	380.6	36.0	912.9	0.4	1828
WW 8	B7 67 26dbb	9.7	8-02-65	Q_a	7.1	2100										
WW 8		16.1	5-15-66		7.9	3013	204.4	274.8	180.0	2.5	19.2	468.5	40.0	1635.5	3.0	2556
WW 9	B7 67 35acb	8.9	8-02-65	Q_a	8.0	3118	200.0	119.2	230.0	11.5	19.7	153.7	220.0	1077.3	17.0	2804
WW 9		9.6	5-15-66													
WW 10	B7 67 35acb	6.7	8-02-65	Q_a	7.1	5250										
WW 10		9.6	5-15-66		7.8	3346	220.0	265.0	210.0	5.5	4.8	561.2	184.0	1334.2	20.0	2748
WW 11	B7 67 35adc	1.8	8-17-65	Q_a		1500										
WW 12	B7 67 35dab	8.2	7-19-65	Q_a	7.5	1800										
WW 12		11.3	5-15-66		8.3	1285	82.5	85.0	80.3	2.0	28.8	297.7	24.0	401.0	5.8	932
WW 13	B7 67 35dba	11.7	8-02-65	Q_a												
WW 13		11.6	5-15-66													
WW 14	B7 67 35dbb1	12.3	8-02-65	Q_a												
WW 14		12.5	1-10-66													
WW 15	B7 67 35dbb2	12.6	8-02-66	Q_a												
WW 15		12.6	1-10-66													
WW 16	B7 67 35ddc		8-17-65	Q_t	7.7	1400										
WW 17	B7 67 35dda	19.5	8-02-65	Q_t												
WW 18	B6 67 2aab	8.6	8-02-65	Q_a	7.6	2223	172.3	172.7	175.0	2.5	0.0	473.4	56.0	976.8	18.0	1892
WW 19	B6 67 1bbb	27.2	9-08-65	Q_t	7.4	1600										
WW 20	B6 67 2adb	14.6	8-02-65	Q_a	7.3	1886	300.6	68.1	225.0	59.0	19.7	344.0	36.0	1057.7	8.0	1732
WW 20			5-15-66		8.0	1874	132.3	155.6	110.0	3.0	38.4	366.0	36.0	768.0	7.7	1544
WW 21	B6 67 1cbc	30.8	9-08-65	Q_a	7.3	1700										
WW 22	B6 67 11aaa	11.8	8-02-65	Q_a	7.9	1886	174.3	90.0	185.0	3.5	21.6	351.4	38.0	769.3	12.0	1596
WW 22		10.0	5-15-66			2000										
WW 23	B6 67 11aac1	12.5	8-02-65	Q_a	7.2	2300										
WW 24	B6 67 11aac2	15.4	8-02-65	Q_a	8.1	2098	162.3	139.8	165.0	4.5	2.4	346.5	38.0	928.3	8.7	1808
WW 24			5-15-66		8.2	1945	230.0	205.0	140.0	4.0	38.4	278.2	40.0	1405.0	5.3	2360
WW 25	B6 67 12bbb2	8.3	8-17-65	Q_a	7.3	2770										
WW 25		9.4	5-15-66													
WW 26	B6 67 12cbb	15,35	8-02-65	Q_c	7.7	3350	220.4	312.5	280.0	6.0	0.0	539.2	100.0	1773.6	12,1	3256
WW 27	B6 67 11ddb	6.20	8-02-65	Q_a	7.8	2314	188.4	200.6	175.0	4.5	0.0	458.7	46.0	1104.5	8.7	2068
WW 27		5.4	5-15-66		8.2	2342	180.4	197.0	145.0	3.5	48.0	356.2	40.0	1039.6	5.8	1948
WW 28	B6 67 11caa	10.4	8-02-65	Q_a	7,2	3100										
WW 29	B6 67 1cdd	22.5	8-17-65	Q_a	7.5	2700										
WW 30	B6 67 14abb1	32.3	8-02-65	Q_a	7.6	2789	334.7	153.2	250.0	4.5	0.0	461.2	66.0	1412.3	20.1	2636
WW 30		31.4	5-15-66		7.6	2905	256.5	223.7	220.0	4.0	0.0	488.0	64.0	1510.4	9.7	2904
WW 31	B6 67 14abb2	30.0	8-02-65	Q_a	7.7	2302	274.5	104.6	205.0	10.5	0.0	470.9	40.0	1028.8	7.0	2020
WW 32	B6 67 14baa	11.4	8-02-65	Q_a	7.1	2700										
WW 33	B6 67 14cab	7.8	8-02-65	Q_a	7.7	2536	320.6	125.2	205.0	5.5	0.0	458.7	44.0	1223.8	5.2	2292
WW 34	B6 67 14dbc	18.4	8-02-65	Q_a	7.7	2050	270.5	91.2	165.0	4.5	0.0	348.9	42.0	959.6	5.1	1760
WW 35	B6 67 13ccc	22.6	8-02-65	Q_a	7.3	1400										
WW 36	B6 67 14ccc	5.1	8-02-65	Q_a	7.6	1000										
WW 38	B6 67 15dba		8-17-65	Q_a	7.5	1550	200.4	54.7	155.0	3.5	0.0	409.9	34.0	565.4	17.5	1284
WW 39	B6 67 15dbb		8-17-65	Q_a	7.2	1400										
WW 40	B6 67 3aad	5.8	8-02-65	Q_c	7.3	2700	613.2	29.2	155.0	1.5	0.0	441.6	42.0	1441.9	0.9	2620
WW 41	B7 67 34ddd	11.7	8-02-65	Q_c	7.5	6068	627.3	473.0	712.5	10.5	0.0	605.1	422.0	3774.3	14.9	6964
WW 41		16.6	5-15-66		7.5	7361	460.9	644.6	740.0	9.0	4.8	653.9	240.0	4282.1	10.8	7484
WW 42	B7 67 36dbb	7.7	8-17-65	Q_{sd}	7.5	1100										
WW 42			5-15-66		7.7	1168	82.5	72.5	62.5	2.0	4.8	312.3	20.0	371.3	10.2	796
WW 43	B6 67 11cdd	11.6	8-02-65	Q_a	7.2	2430										
WW 44	B6 67 12bbb	12.8	8-02-65	Q_a	7.1	3400										
WW 45	B6 67 11ccc	3.3	8-02-65	Q_c	7.5	2789	350.7	74.2	295.0	8.5	0.0	519.7	204.0	911.1	113.4	2292
WW 45		10.0	5-15-66		8.0	2785	162.5	152.5	253.0	3.0	33.6	458.7	148.0	959.0	10.2	2232
WW 46	B6 67 14bca	1.2	8-02-65	Q_a	7.2	2700										
WW 51	B7 67 36bcb	10.0	8-02-65	Q_{sd}	7.3	1600										
WW 52	B7 67 36cdd1	9.8	8-02-65	Q_{sd}	7.5	1600										
WW 53	B7 67 36cdd2	3.5	8-02-65	Q_{sd}	7.4	1300										
WW 54	B6 67 1aaa	6.2	8-02-65	Q_{sd}	8.8	112	14.0	9.7	2.5	1.5	14.4	29.3	6.0	25.5	1.7	36
WW 54		6.0	5-15-66			180										
WW 55	B7 67 25ccc		8-17-65	Q_{sd}	7.5	1300										
WW 56	B7 67 25ccd	12.1	8-02-65	Q_{sd}	7.8	1294	180.4	65.7	49.0	1.5	0.0	405.0	20.0	396.7	21.2	972
WW 56		15.6	5-15-66		7.7	1338	68.1	138.6	58.5	2.0	4.8	424.6	20.0	430.6	0.6	1040
WW 57	B7 67 25dcc	11.7	8-02-65	Q_{sd}	7.3	1550										
WW 58	B6 67 2ccc	7.9	8-02-65	Q_c												
WW 59	B6 67 11bbb	8.2	8-02-65	Q_c	7.5	3730										
WW 60	B6 67 10ada	3.4	8-02-65	Q_c	7.3	4070										
WW 62	B6 67 15bab	14.3	8-02-65	Q_t	7.3	1350										
WW 62		15.0	5-15-66		7.8	1494	117.5	97.5	88.0	2.0	9.6	405.0	24.0	511.2	0.0	1136
WW 63	B6 67 15bdb	10.9	8-02-65	Q_a	7.2	1350										
WW 65	B7 67 26caa		8-17-65	Q_c		3730										

TABLE II--Analysis of surface water from the Severance Basin.

Results in parts per million, unless otherwise indicated. Location refers to point where sample was taken.

Location	Source	Date Sampled	pH	Specific Conductance mmhos x 10^6	Calcium	Magnesium	Sodium	Potassium	Carbonate	Bicarbonate	Chloride	Sulfate	Nitrate	Total Dissolved Solids
B7 67 23dbd	Spring	8-02-65	8.2	1244	144.3	54.7	88.0	1.5	14.4	390.4	34.0	369.5	5.9	868
B7 67dcb	Loop Lake	12-18-65	8.1	2248	202.4	192.1	160.0	9.0	12.0	212.3	32.0	1371.9	1.1	2248
B7 67 26aac1	Eaton Canal	5-15-66	7.7	232	28.1	17.0	8.8	0.5	4.8	87.8	8.0	58.5	0.0	164
B7 67 26aac2	Spring	5-15-66	8.1	2643	280.6	182.4	160.0	4.0	33.6	224.5	36.00	1473.2	0.0	1850
B7 67 26acc	Slough	1-10-66	8.1	2008	228.5	133.8	245.0	6.7	14.4	378.3	42.0	1162.1	3.0	2008
B7 67 26acc	Slough	5-15-66	7.7	1770	127.5	137.5	160.0	4.5	4.8	346.5	36.0	860.2	2.9	1636
B7 67 26bdc	Brine Pit	8-02-65	8.2	32068	116.2	80.3	10900.0	700.0	312.0	1098.0	4580.0	16346.0	0.9	31916
B7 67 26ccb	Brine Pit	8-02-65	9.0	37413	76.1	124.0	13300.0	900.0	516.0	390.4	2980.0	24423.0	1.7	40588
B7 67 34ccc	Windsor Reservoir	12-03-65	8.1	848	80.2	59.6	55.5	2.5	2.4	112.2	10.0	403.3	0.6	636
B7 67 35dbb	Grass Reservoir	8-02-65	8.3	729	120.2	31.6	26.0	4.5	12.0	139.1	12.0	279.0	1.4	540
B6 67 2daa	Law Reservoir	12-03-65	8.1	1795	140.3	155.6	135.0	5.5	12.0	214.7	24.0	1004.9	4.2	1764
B6 67 2ddc	Slough	1-10-66	8.2	2147	162.3	165.4	245.0	5.5	24.0	363.6	30.0	1112.5	3.0	1828
B6 67 12aaa	Lake	8-02-65	8.3	4359	250.5	357.5	215.0	32.0	9.6	124.4	70.0	2163.5	1.4	4300
B6 67 14caa	Manure water	8-02-65	8.3	10203	200.4	316.2	550.0	2237.5	21.6	278.2	190.0	8036.6	10.2	11552
B6 67 14cbc	Slough	1-10-66	8.3	2103	180.4	145.9	245.0	5.5	26.4	378.2	34.0	1122.6	3.3	1716

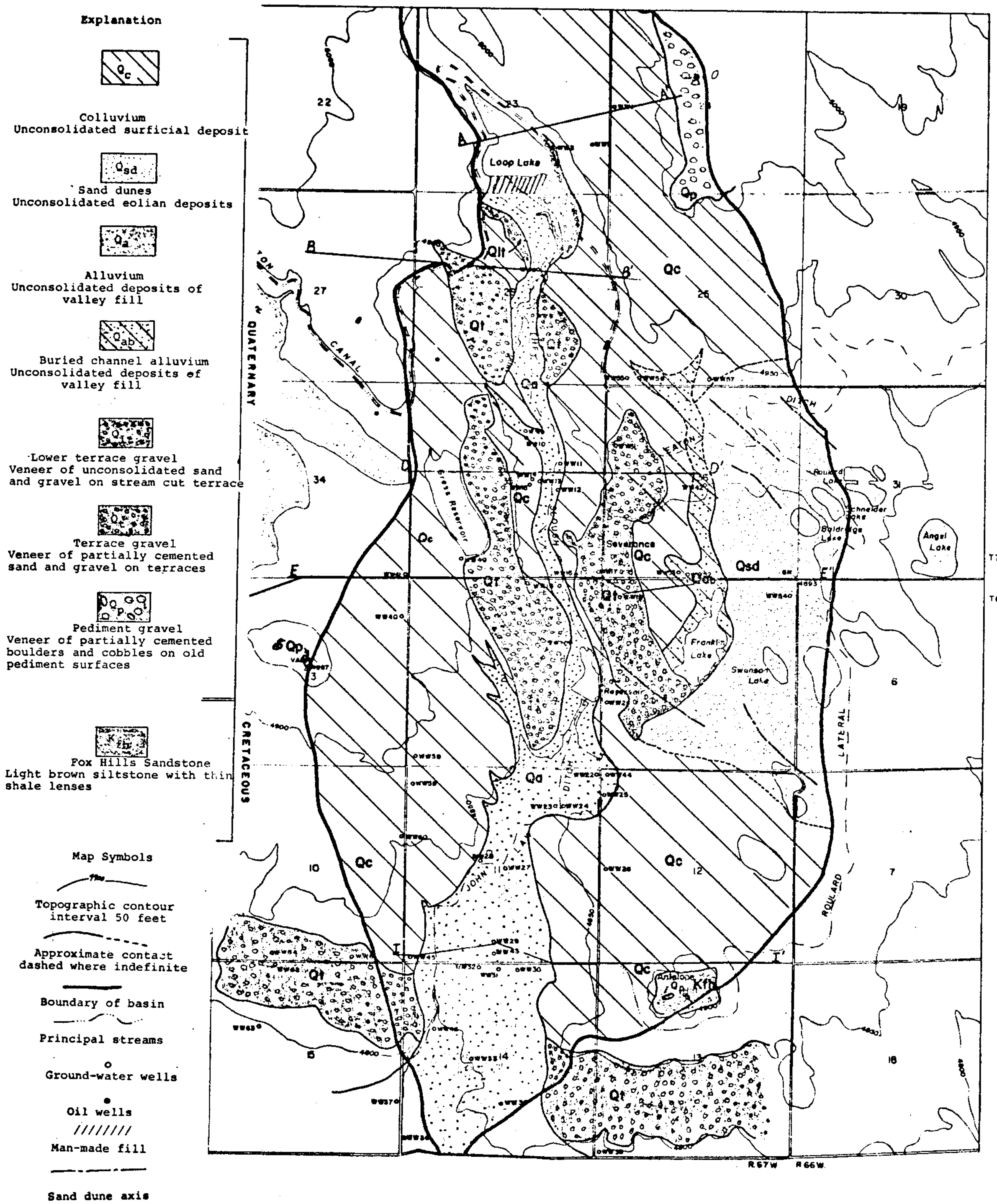
principal contributions of the imported irrigation water have been the recharge of the basin ground water supply and the leaching of soluble salts from the soil.

3. Natural conditions in the basin have prevented soil salinization for approximately 75 years of irrigation. In the area of low permeability and high soluble salt in the soil, there is insufficient ground water for irrigation purposes; therefore, the relatively pure water of Eaton Canal and Windsor Lake is used for irrigation. These waters effectively leach soluble salts from the soil and add them to the ground water. Due to a lack of drainage, the groundwater quality is poor but the soils are essentially leached of salt. This is the case in areas covered by colluvium and in the irrigated part of the upper terrace deposit.

4. The zone of alluvial fill has sufficiently high soil permeability to allow salts in the soil to be leached by percolating meteoric waters. Although there is sufficient ground water in the fill for irrigation, there is a buildup of salt in the soil and a gradual degradation of ground water quality due to recycling of irrigation waters. If drainage were not effective in this area, a saline soil condition could result. At present, these soils have the highest electrical conductivity in the basin.

5. In the zone of sand dunes, Eaton Canal water is used to irrigate a high permeability soil with a low salt content. Ground water in this area has the lowest salt concentration in the basin.

6. The chemical quality of the "Slough" (Plate 2) is directly influenced by the quality of water from Loop Lake and from the springs in the lower terrace gravels. The "Slough" is effluent only



GEOLOGIC MAP

SEVERANCE BASIN

by M.R. McComas

JUNE 1966

Plate 2

immediately below Loop Lake; south of this area the "Slough" is influent.

The factors contributing to the chemical quality of ground water in the Severance Basin have been only generally evaluated in this investigation. Several recommendations for the improvement of ground water quality are listed below:

1. In areas where ground water is lost by evaporation and residues of salts accumulate in the soil, drainage techniques can be used to prevent concentrations of salts.

2. Brine pits should be lined with impermeable material, such as bentonite, to prevent the addition of brine salts to the soil and ground water.

3. Community regulations should prohibit the use of the "Slough" as an open sewer. Cattle feedlots and outdoor facilities should not be allowed to drain into the "Slough."

Factors which may degrade the water quality have been evaluated by utilizing only one year's records of water quality. A several years' sampling program to include chemical analysis of water and measurement of water levels would aid in pinpointing some of the degrading factors in the basin. Several years of sampling could also determine how much degradation of the water actually occurs.

<u>Upper Black Hollow Creek Area</u>: <u>Sherman, 1965</u>

Black Hollow Creek lies in the Cache la Poudre drainage approximately 10 miles east of Fort Collins. The portion included in this investigation may be roughly defined as that portion of the Black Hollow subwatershed north of the Eaton Ditch. (See Plate I)

Surface water and shallow water wells in the southern portion of this area (and further downstream) are often so highly mineralized that they are unfit for human or stock consumption. The investigation was begun in an effort to locate the origin of the various contaminants.

In the southern portion of the area (that region south of the Pierce Lateral) irrigated farming is practiced. The water used is diverted from the Cache la Poudre River. There are a few shallow wells of generally poor quality, some of which are being used for stock or domestic purposes.

North of the Pierce Lateral only "dry-land" farming is practiced. There are no shallow wells. Domestic and stock wells are developed from depths ranging between 300 to 700 feet. This water is potable, and reasonably similar to wells in other areas developed in the Fox Hills Formation or the Pierre-Fox Hills Transition Zone.

An inventory of the shallow wells in the area indicates that there are too few wells for "simple" water level/water quality mapping.

With few "man-made" contaminant sources in the major portion of the area, a more strictly geologic approach to the study was indicated.

The northern portion of the investigation area has little or no "foreign" water added to the hydrologic cycle. It therefore serves as an excellent contrast to the southern portion and to simultaneous investigations in the lower Black Hollow drainage.

Field mapping indicates that the drainage lies within the Pierre-Fox Hills Transition Zone and the Fox Hills Formation. Bedrock exposures all dip gently to the east, and the valley was apparently developed on the dip slope. The base of most cutting appears to be an iron/calcite concretionary horizon well exposed in the western margin of the report area. The most active erosion seems to have taken place in a thin-bedded sandstone-shale sequence that lies between the resistant concretionary horizon and the base of the Milliken Member of the Fox Hills (the uppermost unit).

Vertical exposures of this section outside the drainage area show high percentages of blue or black shales as well as several thin beds of gypsum.

Several pediment remnants occur in the area. There are possibly two pediment surfaces; they are tentatively identified as the Timnath and Coalbank surfaces. Bases of the pediment gravels are well cemented with a calcareous cement which often resembles commercial concrete. The distribution of these remnant gravels and the size of material associated with them gives some indication of the previous erosional capacity of the stream.

Gravel horizons other than those associated with the pediments seem to be confined to the course of the present drainage.

There is an extensive and well developed buried soil in the area. It contains a well developed caliche horizon, and also contains crystalline gypsum in several localities. The "modern" soil throughout the area also shows well developed caliche horizons.

These geologic factors offer feasible explanations for much of the mineral content associated with ground and surface waters in the lower Black Hollow drainage.

Recharge of the shallow ground water occurs through precipitation and the spreading of "imported" irrigation water. This water must percolate through the soil, thereby acquiring minerals from the caliche and gypsum layers. Water in contact with the shale bedrock will be further enriched in mineral content.

The irrigation practices in the southern portion of the drainage basin have served to raise the water table. In some areas, encroachment upon the buried soil horizon and even the modern soil has caused solution of the gypsum and caliche associated with these soils.

Boxelder Creek Basin: Stollar (1969, Mahar (1969)

Results of an investigation on water quality in Boxelder Valley by White (1964) are quoted in the following paragraphs to provide a framework of information which has led to more recent hydrogeological studies in Boxelder Valley by Stollar (1969), and Mahar (1969).

"The Lower Boxelder Creek Valley is located in the northern part of the Colorado Piedmont in north-central Colorado (See Figure 4.) Snowmelt runoff from the adjacent Southern Rocky Mountain Front Range is diverted to the valley for irrigation purposes by an extensive network of canals and reservoirs. To supplement diversion water allotments and the 14.8 inch mean annual precipitation, ground water is pumped from the valley's alluvial deposits.

"Total dissolved salt concentrations in the valley's water supplies range from 100 to 6000 ppm. At initial diversion points (near the north of the Poudre Canyon) Cache la Poudre River and Colorado-Big-Thompson Project waters contain high bicarbonate content but less than 100 ppm dissolved salts. Where diversion waters flow out of crystalline rocks of the Front Range and over less resistant flanking sediments, sulfate replaces bicarbonate as the dominant anion and salt concentration increases. During periods of storage in valley reservoirs diversion water salinity further increases to the 500-2000 ppm range.

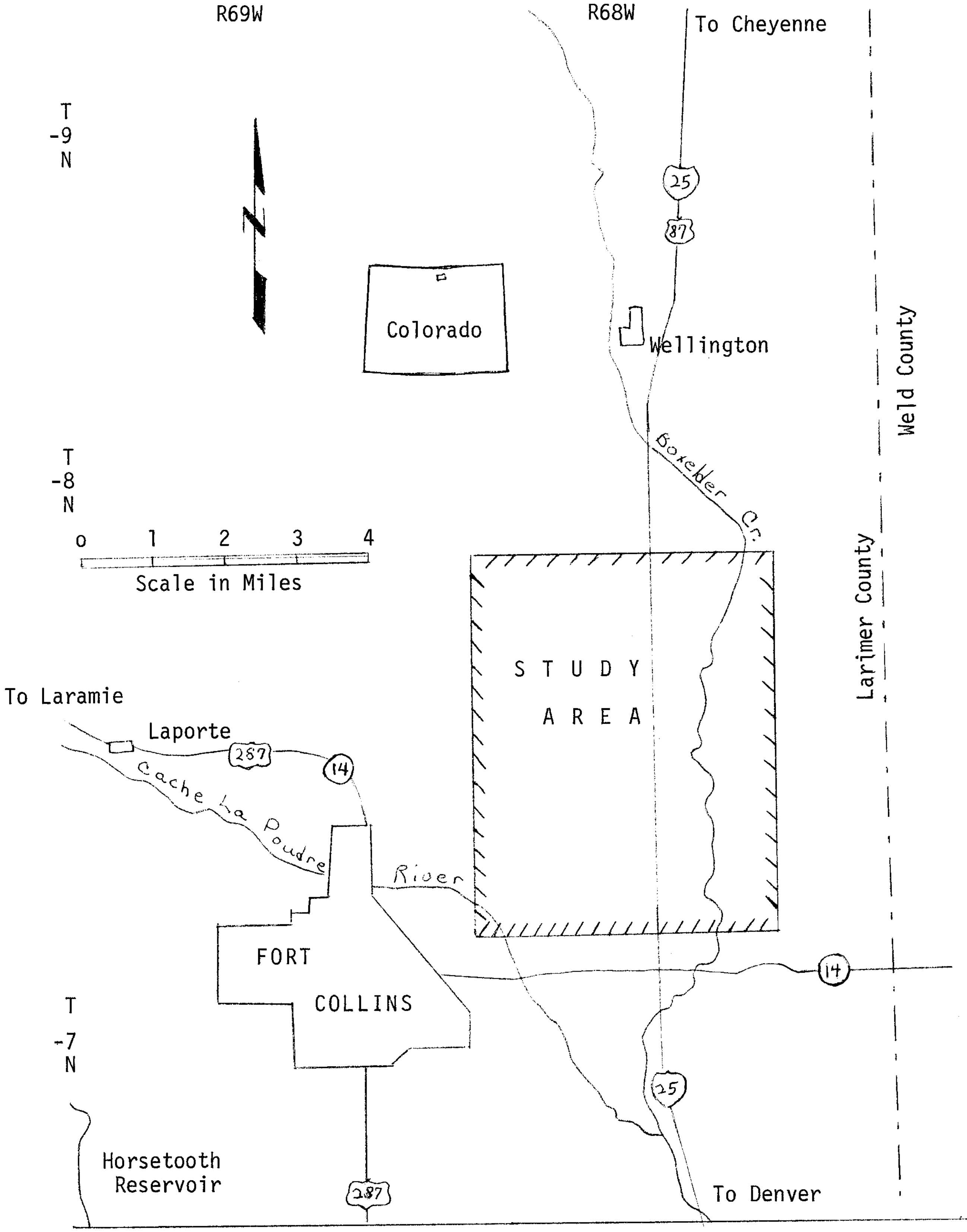


Figure 4. Location map of the study area, Lower Boxelder Creek Valley, Colorado

"Boxelder terrace deposits store and produce most of the valley's ground water supply. The ground water reservoir is recharged mainly by downward percolating diversion water, precipitation, and Boxelder Creek flow and underflow. Evapotranspiration losses from applied surface waters plus leaching of soluble constituents of surficial deposits and Pierre shale bedrock result in high ground water salinity (total dissolved salt in 50 samples average 2385 ppm). Ground water salinity generally increases down valley, but low salinity zones are maintained down gradient from irrigation canals reflecting recharge and refreshment by relatively low salinity canal water. High salt concentrations in ground water contribute to local problems of stock water toxicity and salt accumulation in soils. Full evaluation of these problems necessitates further research."

Geophysical investigations in the Boxelder Creek Valley were carried out by Stollar (1969) in order to evaluate the applicability of both seismic refraction and electrical resistivity techniques for determining aquifer characteristics. An area of about twenty square miles in the Lower Boxelder Creek Valley was chosen for the geophysical studies (See Figure 7)

Results of the electrical resistivity survey were inconclusive. Using a Wenner electrode array (equal spacings between current and potential electrodes) and basin interpretations on plots of cumulative apparent resistivity versus electrode spacing, poor correlations were ottained between resistivity profiles and logs of nearby wells. Two factors have probably contributed to the failure of the resistivity studies:

1. Ground water quality is poor in some portions of the Lower Boxelder Creek Valley. The high dissolved solids content in the water reduces the contrasts in resistivity between the various bedrock and alluvial lithologies. Without sufficient contrasts in resistivity between consecutive earth layers, interpretations cannot be made.

2. Interpretation of resistivity data by means of cumulative resistivity plots may be valid only under limited circumstances. Although revised interpretations were beyond the scope of this study, trial use of theoretical curve matching procedures yielded promising results.

Application of seismic refraction techniques proved considerably more fruitful than the resistivity survey. To analyse the distribution and ranges of seismic velocities, relative frequency histograms were constructed (Figure 5). Perhaps the most significant contribution of this study was the documentation of the usefulness of seismic interpretations based on wave front diagrams. These diagrams are very useful when seismic depth or velocity determinations do not agree with geologic inference or nearby geologic control. In such cases, the assumptions made in seismic refraction formulas must be studied to establish whether or not they are satisfied. This necessitates the use of geologic bias--if the occurrence of a buried low speed layer, a layer of less than minimum thickness, or a refracting layer that is not a planar surface is geologically feasible, it must be considered in the interpretation. An example of a wave front diagram is shown in Figure 9. Use of the refraction seismic technique enabled the investigator to obtain sufficient data on the configuration of the buried bedrock surface to construct a contour map of this surface (See Figure 7).

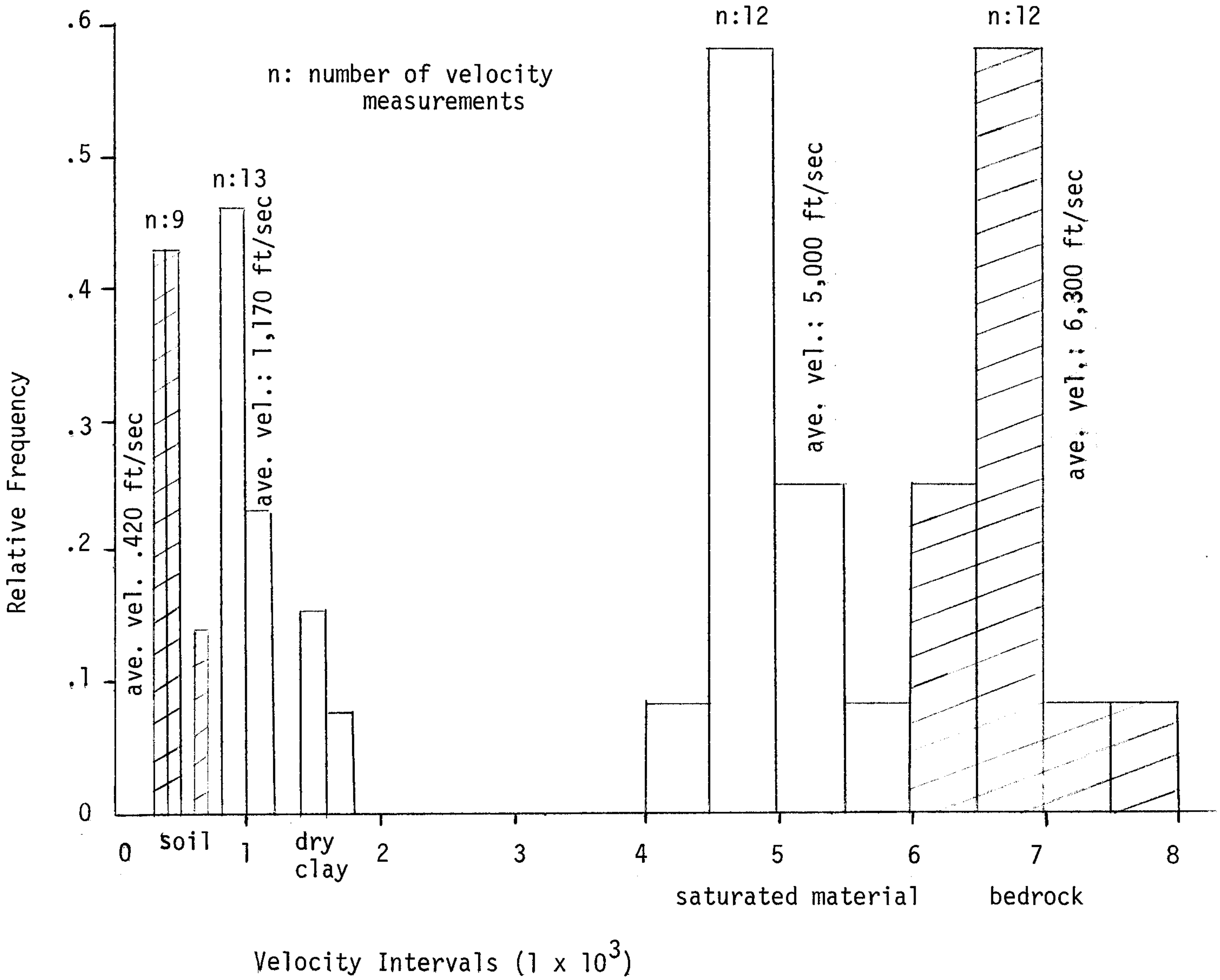


Figure 5. Relative frequency histogram indicating the distribution and ranges of seismic velocities.

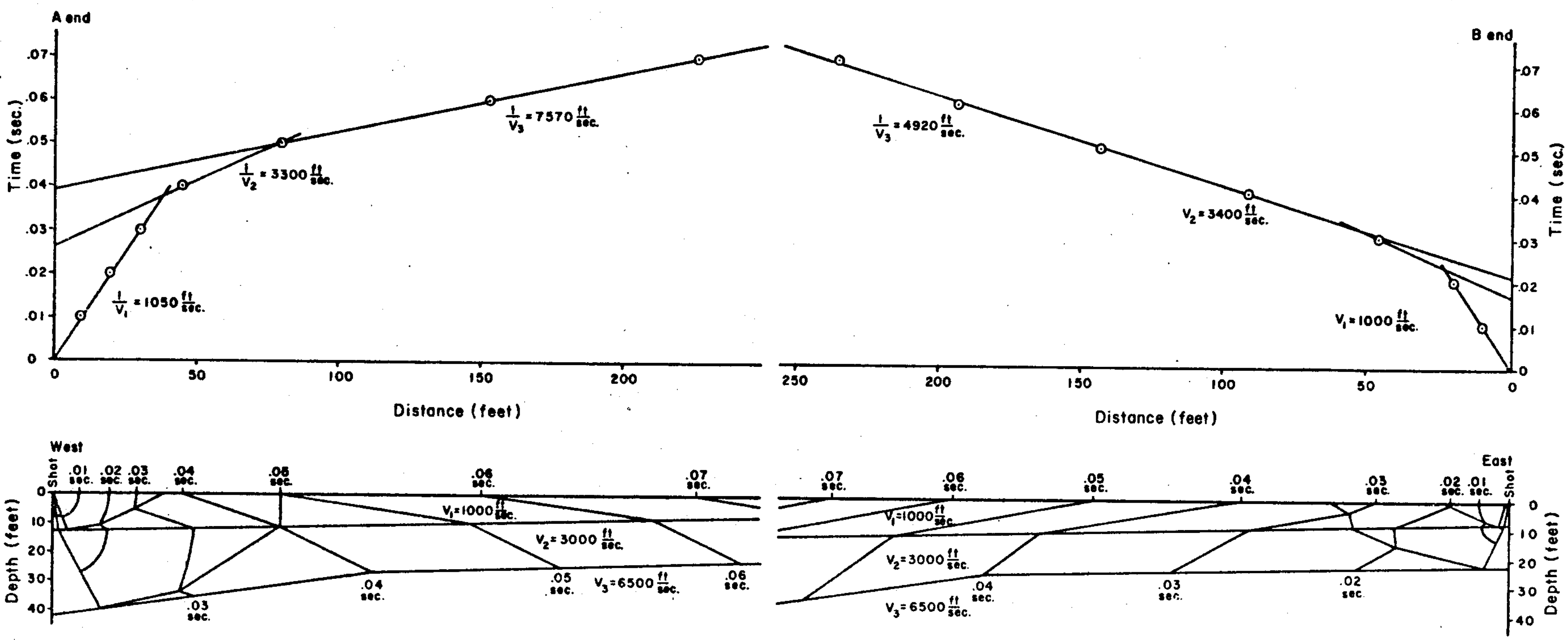
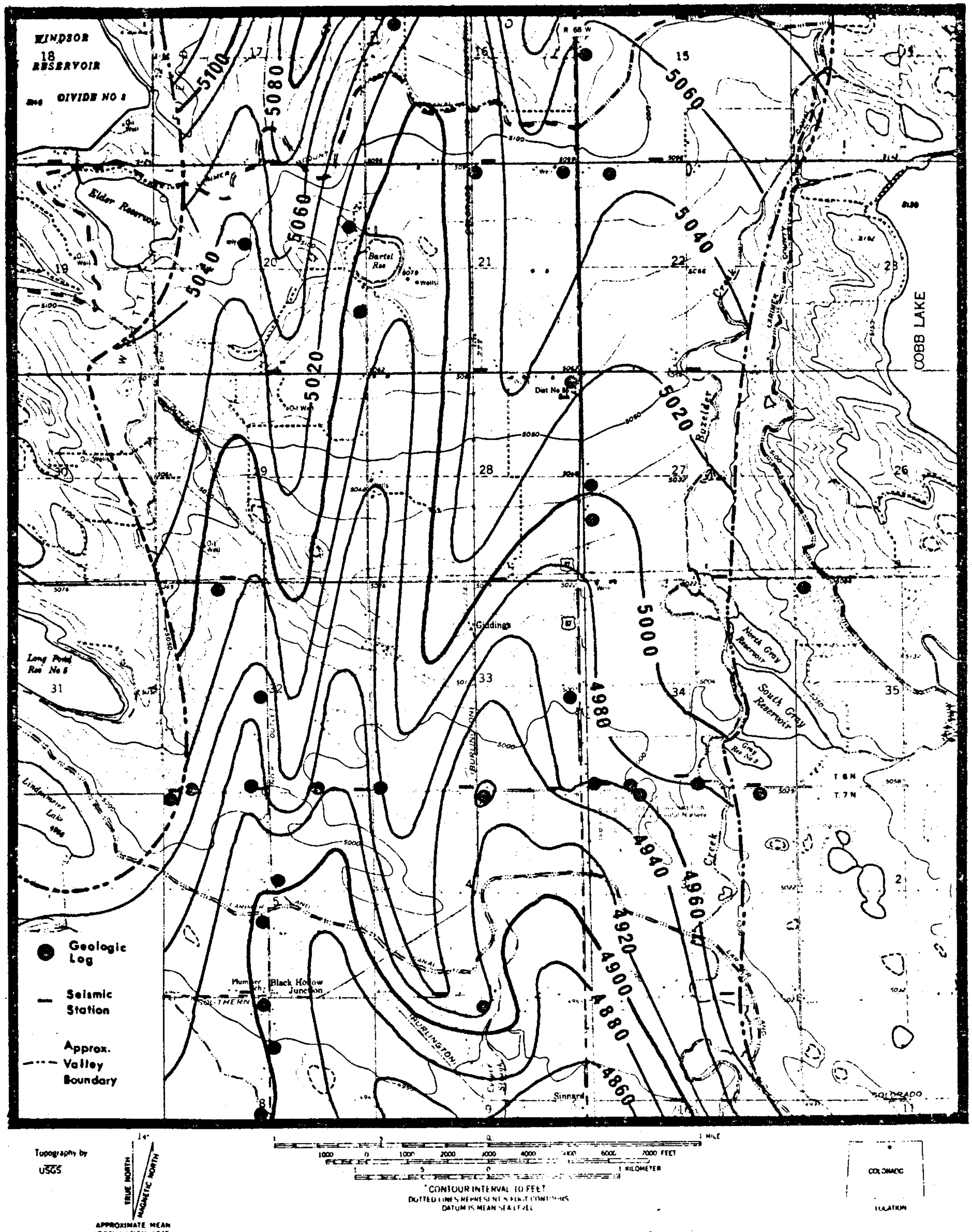


Figure 6. Wave front diagram and derived travel-time graph indicating a non-planar refracting surface for station 10.



—5000— Bedrock contour line.
Contour interval, 20 feet.

Figure 7. Bedrock elevation contour map of the Lower Boxelder Creek Valley, Colorado.

The multiple coalescing bedrock channels in the Lower Boxelder Creek Valley provide a complex framework which must be understood for investigations of ground water flow patterns and the distribution of poor quality ground water in the valley.

A separate research project on the hydrogeology of the Lower Boxelder Creek Valley has been completed by Mahar (1969). This study was conducted to evaluate the feasibility of using lithologic logs of well in the area to estimate permeability coefficients of the alluvial aquifers in the valley. Storage and permeability coefficients are generally determined by analysis of pumping tests. However, interpolation and extrapolation of these coefficients to untested portions of the aquifer are tenuous due to the variability of alluvial materials and low density of pumping test sites. Numerous wells have been logged in Boxelder Creek Valley. Thus the area provided an excellent site for this project. The geologist who logged the wells supplied information on criteria used for lithologic descriptions. Using this information, quantitative estimates of sizes and of their relative abundances were assigned to each lithologic description. From these estimates, approximate grain size distribtuion curves were constructed for the various lithologic descriptions. From these curves, permeability coefficients were estimated using type curves. These permeability coefficients were then weighted and combined to obtain an estimate of the effective permeability of the total aquifer at that point.

An electric analog was constructed so that ground water responses could be modeled using the permeability data obtained from lithologic descriptions. Preliminary results of this research indicate that significant improvements in model performance are possible if pumping test data are supplemented by permeability estimates based on lithologic logs.

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