THESIS

INORGANIC WATER QUALITY OF THE LITTLE SOUTH POUDRE WATERSHED WITH A SECTION ON THE PRECAMBRIAN PETROLOGY OF THE UPPER FALL CREEK AREA

Submitted by

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In partial fulfillment of the requirements
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August, 1966

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ABSTRACT

INORGANIC WATER QUALITY OF THE LITTLE SOUTH POUDRE WATERSHED WITH A SECTION ON THE PRECAMBRIAN PETROLOGY OF THE UPPER FALL CREEK AREA

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.

The low total dissolved solids content, ranging from 28 to 75 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 4½ 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.

For greater effectiveness in interpreting and analyzing water-quality data, the Little South Poudre has been divided into sub-watershed units. Generally, mean values of dissolved mineral concentrations are consistent throughout these

basins; however, certain exceptions do occur. In Beaver Creek and the Little South Poudre (mainstem) anomalous iron and copper concentrations, respectively, were recorded. These anomalies can probably be attributed to an iron "fixing" bacteria and zones of copper mineralization, respectively. High concentrations of dissolved solids in ground water feeding Fish and Pendergrass Creeks probably accounts for values of total dissolved solids that were well above the overall mean for the watershed.

Fall Creek was selected as a geologic control area for the inorganic water-quality study. The upper Fall Creek portion of the Little South Poudre watershed consists chiefly of a sequence of Precambrian biotite schist, biotite-quartzo-feldspathic gneiss, granite and amphibolite. Metamorphic rocks in the area have probably undergone several stages of regional metamorphism up to the rank of almandine-amphibolite facies. This rock suite appears to be representative of the geology of the upper part of the Little South Poudre watershed and thus proved invaluable in making geologic-hydrologic interpretations in the inorganic water-quality study. Glacial deposits in the Fall Creek sub-watershed suggest that the area has been subjected to several major and minor episodes of the Late Pleistocene (Wisconsin) to Recent glaciation.

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August, 1966

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INTRODUCTION

Purpose of Investigation

The primary purpose of this study is the analysis of inorganic water-quality in surface and interrelated ground waters within the Little South Fork of the Cache La Poudre River, Larimer County, Colorado. A geochemical base metal anomaly survey was also conducted in an attempt to locate zones of mineralization within the watershed. A sub-watershed area (upper Fall Creek) was geologically mapped in detail to provide a limited study area for the evaluation of bedrock control on water quality in that region.

Selection of the Little South Poudre watershed as a study area was based on several important considerations. Since two weather stations and numerous gaging stations are located on the Little South Poudre and its tributaries, the watershed has excellent hydrologic control. This watershed is fairly typical of the high mountain drainage in the region and is sufficiently large to provide a meaningful sample. Furthermore, the Little South Poudre is under intensive investigation by several departments at Colorado State University (Agronomy, Watershed Management, Fishery Science, etc.), and it is hoped that this investigation will supplement previous work and lead to a better understanding of various watershed parameters and their effects.

Location of the Area

The Little South Poudre is one of the larger tributaries of the Cache La Poudre River which in turn is tributary to the South Platte River. The watershed covers nearly 105 square miles in Larimer County, Colorado, approximately 30 miles west of Fort Collins and 14 miles north of Estes Park (Plate 1). The area is situated within Townships 6, 7 and 8 North and Ranges 72, 73 and 74 West (approximate latitude and longitude: 40° 29' to 40° 42' N. and 105° 26' to 105° 44' W.). The southern part or headward portion of the watershed, including a major portion of the Fall Creek sub-watershed, lies within Rocky Mountain National Park.

The Little South Poudre drains part of the east flank of the Mummy Range in the north-central Colorado Front Range. The area ranges in elevation from 6,550 feet at the confluence of the Little South Poudre with the Cache La Poudre on the north to 13,400 feet, at the summit of Rowe Peak, on the south (mean elevation 9,700 feet). The watershed is characterized by alpine regions, rugged glacial topography and heavily forested slopes. Most of the tree cover consists of Lodgepole Pine with some stands of Spruce-Fir, Ponderosa Pine and small areas of Aspen.

Although no all-weather roads traverse the area, numerous access roads are available during the summer months.

The climate of the Little South Poudre area is typical of alpine to sub-alpine areas in Colorado. The mean annual precipitation is estimated to be between 18 and 22 inches. This estimate is based on precipitation records from

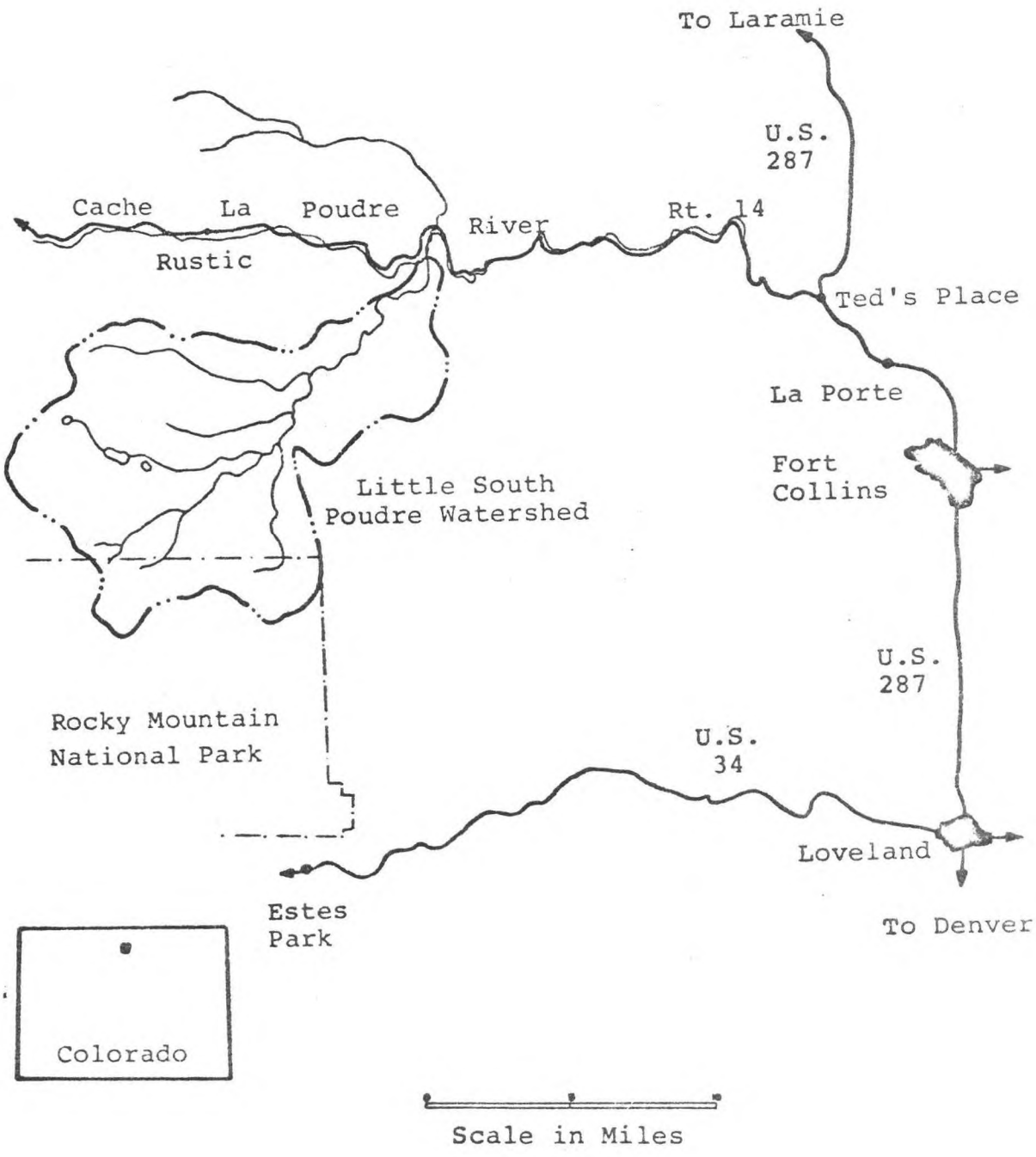


Plate 1. Location map of the Little South Poudre Watershed, Larimer County, Colorado.

surrounding watersheds as well as data from the Pingree Park station. Of this amount, about 60 percent is snowfall the rest coming as brief summer showers. Temperature extremes range from -45° F to 83° F (Pingree Park Weather Station records).

Methods of Investigation

Field work was conducted from June through September 1965 and intermittently from December through June 1965-66. Water samples were collected systematically from the Little South Poudre drainage (Plate 3) and from various springs. Sample procedures used are those discussed in Rainwater and Thatcher (1960) with sample collections made at approximately one mile intervals on the Little South Poudre (mainstem) and 1½ mile intervals on its tributaries. Iron content, heavy metal content, pH and temperature change spontaneously when samples are stored, thus necessitating field analysis of these parameters. The collection of samples in polyethylene bottles facilitated transportation and prevented contamination.

Detailed geologic mapping was conducted on Forest Service aerial photographs enlarged to a scale of 1:14044, and later transferred to 7½ minute United States Geological Survey topographic sheets (Commanche Peak and Pingree Park Quadrangles). Representative samples of the several bedrock units were obtained for petrographic analysis. Geologic studies also included the mapping and interpretation of glacial materials which cover a major portion of the headwater regions of the Little South Poudre.

Water sample tests included quantitative analyses for ionic concentration of the following 14 chemical elements: silica (SiO_2), iron (Fe^{++}), calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, boron, aluminium and copper. The method of analyses included the use of a Hach DR colorimeter and various wet chemical methods as described by Rainwater and Thatcher (1960). Detection of heavy metals was made by use of the dithizone dye concentration method (Ward, Lakin and Canney, 1963) which is described in the appendix.

Modal analyses (Table 6) of thin sections prepared from representative rock samples were conducted utilizing a petrographic microscope with an integrating mechanical stage and a nine bank Lab Count Denominator. Determination of plagioclase composition was made through the combined use of refractive index determination with immersion oils and the Michel-Levy twin method (Kerr, 1959, p. 257).

Staining techniques were utilized to distinguish potash from plagioclase feldspars.

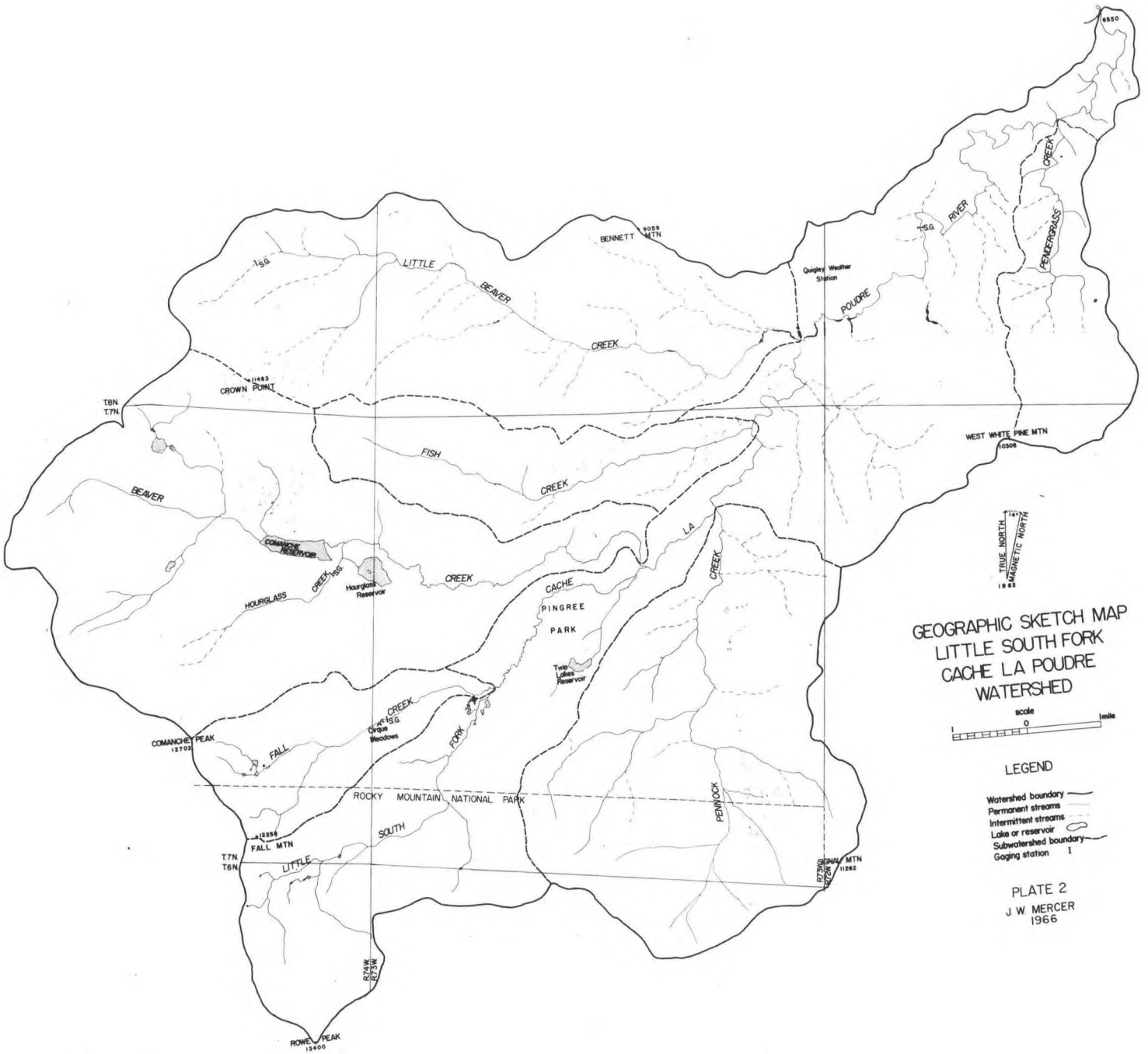
Previous Investigations

Little detailed geologic work has been conducted in the area. Lovering and Goddard (1950) carried out general reconnaissance mapping of the Front Range; however, their work was concerned mainly with ore deposits and little mineralization is present in the Little South Poudre area. Additional reconnaissance work was done by Boos and Boos (1957) on structural trends in the northern Front Range.

Ray (1940), and more recently Richmond (1953, 1957 and 1960), worked on glacial chronology in areas adjacent to the Little South Poudre.

Detailed mapping is currently being conducted in the Mummy Range under the supervision of Dr's. M. E. McCallum (Colorado State University) and J. S. King (New York State University at Buffalo). Although no published reports are available, several geologic maps have been compiled and a masters thesis was completed in 1966 by Paul Kirst of New York State University.

* The Cooperative Watershed Management Unit, Colorado State University, conducted a watershed analysis of the Little South Poudre in 1962-63 (Johnson and others, 1963). This agency is primarily interested in hydrology and forest supervision and management. In conjunction with the watershed analysis, the unit is presently studying organic water-quality (especially coliform) in an effort to record the effects of extended grazing in mountain watersheds (S. Kunkle, 1966, oral communication). The Watershed Unit has also conducted various snow surveys in the area and is presently studying snow-wind effects and snow evaporation in the Hourglass cirque area (C. Slaughter, 1965, oral communication) (Plate 2).


8550
BENNETT 9059 MTN
LITTLE BEAVER CREEK
1 S.G.
Quigley Weather Station
POUDRE
7 S.G.
RIVER
CREEK
PENDERGRASS
11463
CROWN POINT
T8N.
T7N.
WEST WHITE PINE MTN
10306
FISH CREEK
BEAVER
COMANCHE RESERVOIR
HOURGLASS CREEK
5 S.G.
Hourglass Reservoir
CREEK
LA CACHE LA PINGREE PARK
CREEK
Twin Lakes Reservoir
TRUE NORTH
MAGNETIC NORTH
1962
GEOGRAPHIC SKETCH MAP
LITTLE SOUTH FORK
CACHE LA POUDRE
WATERSHED
scale
1 0 1 mile
LEGEND
Watershed boundary
Permanent streams
Intermittent streams
Lake or reservoir
Subwatershed boundary
Gaging station 1
PLATE 2
J. W. MERCER
1966
COMANCHE PEAK
12702
FALL
CREEK
2 S.G.
Cirque Meadows
FORK
ROCKY MOUNTAIN NATIONAL PARK
PENNOCK
12256
FALL MTN
SOUTH
LITTLE
T7N
T6N
R74W
R73W
R73W
R72W
SIGNAL MTN
11262
ROWE PEAK
13400

CHEMICAL CHARACTER OF WATER

Extensive weathering of rock typically results in three kinds of product: (1) residual minerals, (2) insoluble authigenic minerals, and (3) soluble compounds. Since the first two types of material are usually immobile, they tend to accumulate at the site of weathering. On the other hand, soluble products are removed by percolating ground water and overland flow. This removal of soluble salts is called "chemical degradation", and the term should be applied only to the removal of rock material by chemical erosion and the subsequent transport of dissolved products (Hembree and Rainwater, 1961, p. E-1).

As a function of chemical degradation, all natural waters contain dissolved mineral matter. Water in contact with soil and rock, even if for only a few hours, will normally dissolve some material. The quantity of dissolved mineral matter depends primarily on the type of rock or soil with which the water has been in contact. Since most streams are fed by both surface runoff and ground water from springs or seeps, these streams should reflect the character of the rocks and soils through which they percolate or over which they travel. Utilizing this premise, many workers have been able to show that each rock type yields ground water and surface water having a distinct chemical character.

Legrand (1958), working in igneous and metamorphic rocks in North Carolina, and Miller (1961), studying Precambrian crystallines and Paleozoic sediments in New Mexico, were able to show the development of a uniform concentration of solutes in water draining a single rock type. They were also able to classify various waters by the rock types that they drained (i.e. granite water, diorite water, quartzite water, etc.). Such a relation appears to be useful for predicting the chemical character of composite waters that are derived from several rock types such as those in the Little South Poudre.

INORGANIC QUALITY OF WATER

General Statement

The Little South Poudre watershed is underlain by a sequence of igneous and metamorphic rocks partially covered by a veneer of various surficial deposits (i.e. glacial deposits, alluvium and colluvium). The igneous and metamorphic rocks vary considerably in chemical composition and consequently in solubility; in addition, the glacial material that chokes most of the headwater regions of the Little South Poudre is composed of a heterogenous mixture of fresh rock fragments and clay material. Fresh rock surfaces offer an opportunity for chemical weathering and thus they may provide a ready source for ions to be added to the water. To evaluate the chemical degradation of these materials, the writer collected and analyzed water samples from surface streams and springs within the watershed (See Tables 8 and 9). In addition, several snow samples were collected in headwater regions.

Definition of Terms

Although the general terms used in water chemistry are common ones, some may convey a variety of meanings. As an aid to clarity, several of the terms used in this report are defined.

Total dissolved solids - may be defined by several methods; in this report the term is restricted to total dissolved solids calculated. The calculated total dissolved solids value is the weight sum of chemical constituents reported as parts per million (ppm).

Hardness of water - is a relative term applied when calcium and magnesium are present in sufficient quantity to produce a recognizable effect when soap is used with water in washing. Only extreme variations are described by such terms as "hard" and "soft".

Alkalinity - is the ability of water to neutralize acid and is usually reported in terms of equivalent titratable amounts of bicarbonate, carbonate or hydroxide ions.

Heavy metal content - may include many various trace metals present in water; for this report the term is restricted to copper, lead and zinc.

Basin - has been defined in many ways, but in the Little South Poudre it is used synonymously with sub-watershed.

Additional water quality terminology used in this report is based on definitions employed by Hem (1959).

Surface Water-Quality

The drainage pattern of streams in the Little South Poudre is dendritic. There are approximately 90 miles of permanent streams that give a drainage density (total mileage of permanent streams divided by the area) of 0.856 miles of stream per square mile of area (Table 11). This density indicates a drainage that is well developed with a sufficient

number of channels to effectively drain the watershed. Along with type and amount of vegetation, slope and soil conditions, this "available channel" factor is important in sediment production since insufficient drainage and cover may increase the susceptibility of an area to erosion.

General Chemical Character

Data obtained in this investigation indicates that the inorganic water-quality of the streams in the Little South Poudre is very good ("good" herein meaning water low in total dissolved solids). The mean value for total dissolved solids is approximately 46 ppm. Silica is the predominant chemical constituent in the water and has a mean concentration of 18 ppm. The relatively high value of silica in the streams is not unusual, since the Little South Poudre drains a predominantly igneous and metamorphic terrane.

The water is chemically quite "soft", the mean value of total hardness being 11 ppm (calculated as Ca and Mg). Both calcium and magnesium are among the most abundant metals in nature and are quite common in igneous and metamorphic rocks. Hardness is an important parameter, but its acceptable concentration is highly dependent on the projected use of the water.

The pH of the Little South Poudre is one conducive to bicarbonate (HCO_3) development. Mean values of bicarbonate obtained from the drainage were approximately 17 ppm.

Values of pH tend to be slightly alkaline, averaging around 7.4, and indicate a low CO_2 content. Slightly

alkaline conditions when combined with low water temperature (Summer mean 9° C) retards reaction of water with the elements in the rocks, and would produce water low in dissolved constituents.

Data were obtained in a subsequent winter sampling period in order to establish a relationship between dissolved concentrations and different seasons with correspondingly different stream discharges. As might be expected, there was a general increase in dissolved constituents from 46 ppm in the summer to 59 ppm in the winter (Table 8) coincident with lower discharge rates. pH values, which normally increase with decreasing temperatures, dropped to a mean of 7.2 in the winter while temperatures decreased to a mean of 1.0° C. With the low water temperatures (nearly freezing), pH values obtained are often slightly erratic.

Chemical Character of Sub-Watershed Units

For greater effectiveness in interpreting and analyzing water-quality data, the Little South Poudre has been divided into sub-watershed units (Plate 2). Aside from the trunk stream of the Little South Poudre, they are (from headwaters to mouth): Fall Creek, Beaver Creek, Pennock Creek, Fish Creek, Little Beaver Creek, and Pendergrass Creek. In addition to these, Hourglass, in the Beaver Creek sub-watershed, and Twin Lakes drainage, a minor tributary to the Little South Poudre, are discussed separately even though they are not individual sub-watersheds.

Bicarbonate and silica are by far the most abundant dissolved constituents in the surface water draining the

individual sub-watersheds. Since there is little carbonate mineral in the igneous and metamorphic rocks studied in the Little South Poudre (Table 6), the bicarbonate content must be derived mostly from atmospheric and pedogenic sources. Meteoric water is the common source for atmospheric carbon dioxide and carbon dioxide derived from organic sources (fixed by bacteria) is a common pedogenic source.

Silica is usually the most abundant ion, which is to be expected since the streams drain sub-watersheds composed predominantly of silicate rocks. Many of the small streams in headwater regions carry very large proportions of silica. The silica is probably derived directly from the rocks by the streams at the time of rock decomposition and, therefore, would form a large part of the initial material taken into solution. The chemical reactions involved in decomposition of silicates are highly complex. In a general way they can be represented as hydrolysis reactions in which H^+ from the water replaces metallic cations in the silicate lattice. The lattice is gradually broken up and altered by this process. Clay minerals are formed in most of these reactions, and some of the silicon-oxygen groups of the original mineral are surplus to the new arrangement. The surplus silica and the replaced cations can be considered available for solution (Hem, 1960, p. 52).

Calcium and magnesium are next in abundance in the sub-watersheds. Calcium is the most common alkaline-earth metal in most natural waters. Secondary carbonate minerals offer a possible source for calcium and magnesium; however, few

minerals of this nature were recognized in thin sections of rocks exposed in the Fall Creek sub-watershed. Rankama and Sahama (1950, p. 462) have calculated that in igneous rocks approximately half the calcium occurs in minerals of the amphibole groups and about half in the plagioclase feldspars. These minerals are common constituents in rock units examined in the Fall Creek area (Table 6). It is concluded therefore, that calcium and magnesium were probably derived from plagioclase feldspar, hornblende and biotite.

Other elements, such as aluminium, copper and iron, are found only in trace amounts, and a detailed discussion of their sources is not relevant. These elements are generally found in most of the igneous and metamorphic rocks so prevalent in the Little South Poudre watershed.

Heavy metal (copper, lead and zinc) content analyses indicate a total concentration of these elements of generally less than 10 ppb (parts per billion). Results in the various basins tend to be quite erratic, possibly due to the extreme suseptibility of the dithizone dye method of analysis (Appendix) to contamination.

Snow samples were collected from Fall Creek and Big Beaver sub-watersheds for analytical comparisons. Even though mean dissolved minerals total less than 10 ppm in the snow (atmospheric source), values recorded in the stream less than one quarter of a mile from the snow pack yield values in excess of 30 ppm. This indicates that the water is not in contact with the bedrock very long before noticeable increases in dissolved material can be observed;

however, the concentration does not increase appreciably downstream beyond this zone of initial buildup.

Major portions of the sub-watersheds in the upper Little South Poudre have undergone several major and minor episodes of glaciation. There is undoubtedly a definite hydrologic-geologic interrelationship between the water and glacial materials which must have an influence on the water quality of the area. A full treatment of these influences due to available time is beyond the scope of this report.

Characteristics and abnormalities of inorganic water-quality related to specific sub-watersheds are described below for each separate basin.

Fall Creek Sub-Watershed

Fall Creek was selected as a control area for this study. The geology of the upper part of the sub-watershed was mapped in detail to facilitate comparison of water quality to lithology. Although direct inference is not always made, suggestions as to sources for the dissolved mineral constituents discussed throughout the report are based on modal analysis of rock thin sections from the Fall Creek area along with certain field relationships. Since it appears that the geology of this sub-watershed is representative of the upper reaches of the Little South Poudre, these comparisons should be valid in other sub-watersheds.

Fall Creek is a glaciated watershed with an area of 4.3 square miles. Table 1 lists the concentrations of the principal dissolved mineral constituents.

Table 1. Concentrations of principal mineral constituents in Fall Creek water.

Constituent	*Concentration (ppm) July-August, 1965 Max.	Mean	Min.
Silica	15.9	14.0	12.0
Calcium	6.0	3.2	2.0
Magnesium	5.0	3.0	1.0
Sodium	.7	.5	.3
Potassium	.3	.3	.2
Bicarbonate	13.0	11.0	8.0
Sulfate	3.0	1.4	Tr
Chloride	3.0	1.4	1.0
Nitrate	.5	.2	.1
TDS	38.0	33.0	28.0

*Based on 5 observations

Beaver Creek Sub-Watershed

Beaver Creek drainage includes an area of 22.3 square miles most of which contains evidence of several stages of glaciation.

This watershed contains two major reservoirs, Commanche and Hourglass (Plate 2). Commanche reservoir occupies a major portion of the former channel of the stream in the central portion of the watershed. Influence of the reservoir on the quality of Big Beaver is apparently minimal as can be seen by comparing samples BB-40, above the reservoir, with BB-42, below the reservoir. Mean, maximum and minimum values for the Beaver Creek sub-watershed are listed in Table 2.

Table 2. Concentrations of principal mineral constituents in Beaver Creek waters.

Constituents	*Concentrations (ppm) July-August, 1965 Max.	Mean	Min.	**Concentrations (ppm) December, 1965 Max.	Mean	Min.
Silica	27.4	20.8	14.0	18.6	17.6	16.6
Calcium	7.0	4.8	2.0	8.0	6.8	5.0
Magnesium	6.0	3.4	.0	8.0	4.0	1.0
Sodium	1.9	.9	.5	1.2	1.1	1.0
Potassium	1.3	.6	.4	.8	.7	.5
Bicarbonate	19.0	14.8	11.0	20.0	16.8	10.0
Sulfate	5.0	2.9	1.0	5.0	3.6	2.0
Chloride	3.0	2.4	1.5	3.5	3.0	2.5
Nitrate	.2	.1	Tr	.1	.1	.0
Iron	.3	.1	.1	.4	.2	.1
TDS	56.0	44.0	30.0	51.0	47.0	41.0

*Based on 8 observations
**Based on 4 observations

Several deviations from the other sub-watersheds occur in Beaver Creek. One such deviation is an increase in maximum total dissolved solids in the July-August sampling period. This could be explained simply by the noticeable increase of silica, which could represent temperature effects on solubility or, since ground water is high in silica, an increase in ground water contribution to the stream during the sampling period. The writer feels the former is the most probable explanation.

Below the reservoir, in sample BB-62b (Plate 3), a noticeable increase in iron was detected in a seepage stream tributary to Beaver Creek. Field analysis indicated a concentration of 3.0 ppm which was verified in a subsequent lab analysis. The temperature of the water during this winter sampling period was 9° C, considerably warmer than the overall winter mean of 4° C recorded from Beaver Creek


LITTLE BEAVER CREEK
BEAVER CREEK
COMANCHE RES.
Hourglass Reservoir
HOURGLASS CREEK
FISH CREEK
CACHE LA POUDRE
POUDRE RIVER
PENDERGRASS CREEK
Twin Lakes Reservoir
SOUTH FORK
FALL CREEK
Cirque Meadows
ROCKY MOUNTAIN NATIONAL PARK
PENNOCK CREEK
LITTLE
T8N.
T7N.
T7N.
T6N.
R74W
R73W
R72W
TRUE NORTH
MAGNETIC NORTH
1966
WATER SAMPLE LOCATION MAP
LITTLE SOUTH FORK
CACHE LA POUDRE
WATERSHED
scale
1mile
LEGEND
Watershed boundary
Permanent streams
Intermittent streams
Lake or reservoir
Sample locations
Water ●20
Spring ●SP35
Snow ●SN27
Resampled water loc. (62)
PLATE 3
J.W. MERCER
1966

waters. This "anomalous" concentration was apparently produced by a form of iron-"fixing" bacteria. Evidence for this conclusion is as follows:

1) Exceptionally warm waters favoring bacterial growth.
2) Presence of an orange "slime" covering the rocks in the stream bed.
3) Absence of high iron concentrations in similar seepages draining nearby areas.
4) Presence of an orange discoloration in the water sample caused by suspended material.

Analysis for the bacterial type was conducted; however, these tests yielded inconclusive results.

Pennock Creek Sub-Watershed

Pennock Creek represents an essentially non-glaciated basin including an area of 17.6 square miles. The chemical character of the water (Table 3) draining this area is quite consistent with other sub-watersheds in the Little South Poudre.

Table 3. Concentrations of principal mineral constituents in Pennock Creek waters.

Constituents	*Concentrations (ppm) July-August, 1965 Max.	Mean	Min.	**Concentrations (ppm) December, 1965 Max.	Mean	Min.
Silica	24.6	18.9	12.6	29.6	25.9	23.6
Calcium	9.0	6.0	3.0	8.0	6.5	2.0
Magnesium	9.0	4.7	2.0	9.0	5.7	4.0
Sodium	1.4	1.0	.8	1.5	1.2	.9
Potassium	.8	.6	.5	.8	.7	.5
Bicarbonate	21.0	15.4	8.0	25.0	20.0	13.0
Sulfate	4.0	2.3	1.0	4.0	3.5	3.0
Chloride	4.0	2.2	1.0	3.5	2.9	2.0
Nitrate	.8	.3	Tr	.2	.1	.0
TDS	53.0	43.0	31.0	69.0	58.0	52.0

*Based on 7 observations
**Based on 4 observations

Fish Creek Sub-Watershed

Fish Creek is a small non-glaciated basin containing approximately 6.6 square miles of heavily forested drainage with a paucity of bedrock outcrops. Several soil samples were recorded in the field, all of which were acidic in nature. There was a lack of sufficient observations to construct a maximum, mean and minimum table; therefore, reference is made to Table 8 for general quality values.

Some of the highest values of dissolved mineral constituents were recorded from this basin. Mean values (based on a limited number of observations) of bicarbonate (29 ppm), silica (21 ppm) and total dissolved solids (63 ppm) all indicate substantial increases over mean values from other basins. In the Fish Creek Basin, location probably accounts for this increase. The major source of water supporting the stream flow must be from the ground-water system, since summer snow packs are absent from headwater regions. The ground water is probably trapped in the thick residual materials in the sub-watershed. As pointed out, the basin is also characterized by a thick forest cover which would favor acid conditions and promote more intensive leaching of the rocks.

Little Beaver Sub-Watershed

Little Beaver Creek is a non-glaciated basin which drains approximately 18.1 square miles of the northern part of the Little South Poudre watershed. Available hydrologic control includes a recording gage station, staff gages and weirs scattered along the main stream. Mean, maximum and

minimum values for dissolved mineral concentrations are recorded in Table 4, which includes only July-August observations due to paucity of observations during the winter sampling period.

Table 4. Concentrations of principal mineral constituents in Little Beaver waters.

Constituents	*Concentrations (ppm) July-August, 1965 Max.	Mean	Min.
Silica	21.0	18.8	15.2
Calcium	8.0	5.5	4.0
Magnesium	4.0	3.0	1.0
Sodium	1.3	1.1	1.0
Potassium	.8	.7	.5
Bicarbonate	21.0	19.3	17.0
Sulfate	2.0	2.0	2.0
Chloride	4.0	3.4	2.0
Nitrate	.8	.4	.2
TDS	49.0	46.0	41.0

*Based on 4 observations

Pendergrass Sub-Watershed

Pendergrass Creek basin contains 5.2 square miles and lies about 2 miles above the confluence of the trunk stream of the Little South Poudre with the Cache La Poudre River. Due to limited access in the lower portion of the basin, only one observation was made.

Although not completely representative, the values obtained (Table 8) do show a considerable increase over mean values from other streams. Total dissolved solids (75 ppm) represent the highest value recorded from any of the streams in the entire watershed. As in Fish Creek basin, a lack of summer snow pack resulting in a considerable increase in the

proportion of ground water contribution to stream flow probably accounts for this increase.

Little South Poudre (mainstem) Sub-Watershed

The Little South Poudre sub-watershed herein discussed includes the main Little South Poudre from headwater regions to its confluence with the Cache La Poudre. The area outlined in Plate 2 is the largest sub-watershed unit in the study area and includes 30.9 square miles. The water-quality values (Table 5) may be somewhat ambiguous since concentrations in the trunk stream are controlled considerably by tributary waters emptying into the Little South Poudre; however, they do give an estimate of the water quality.

Table 5. Concentrations of principal mineral constituents in the Little South Poudre (mainstem) waters.

Constituents	*Concentrations (ppm) July-August, 1965 Max.	Mean	Min.	**Concentrations (ppm) December, 1965 Max.	Mean	Min.
Silica	22.6	15.0	8.4	29.6	19.5	15.6
Calcium	7.0	4.4	2.0	11.0	8.4	4.0
Magnesium	9.0	4.0	1.0	10.0	6.6	2.0
Sodium	1.0	.8	.6	1.2	1.0	.9
Potassium	.7	.6	.4	.7	.6	.6
Bicarbonate	21.0	13.7	9.0	25.0	20.1	13.0
Sulfate	5.0	2.2	Tr	3.0	2.7	2.0
Chloride	4.5	2.5	1.0	3.5	3.1	2.5
Nitrate	.3	.1	.0	.3	.2	.0
TDS	48.0	37.0	28.0	67.0	52.0	42.0

*Based on 19 observations
**Based on 7 observations

pH 7.2

An anomalous concentration of copper was detected in SP-12 near Quigley weather station (Plate 2). First indications of a high concentration were obtained in the field

when a concentration of 40 ppb (parts per billion) heavy metals was recorded by analyzing the water using the dithizone dye method. Later lab analysis verified these results indicating a copper concentration of 1.5 ppm which is well over the mean values obtained in other sections of the Little South Poudre watershed. Waters feeding this stream were found to be draining an area mineralized in the copper minerals malachite and azurite. Springs issuing from the zones of mineralization evidently supply the higher concentrations of copper recorded in the small tributary.

Minor Tributaries

Hourglass and Twin Lakes are minor tributaries that are considered separately. The Twin Lakes tributary drains Twin Lake Reservoir, a water supply source for the city of Greeley, and Hourglass tributary is characterized by excellent hydrologic control. Table 8 includes a list of water-quality values obtained from these tributaries.

Snow Water-Quality

General Chemical Character

The bulk of all water supplying the streams of the Little South Poudre is, if not directly, indirectly from snow melt with minor contribution from rainfall. Consequently, four samples were collected from the existing snow pack in headwater regions during the summer. Although these analyses do not indicate the quality of snow as it falls, it does give general chemical character of the snow pack that

is supplying melt water to the streams. The mean values of total dissolved solids and principal mineral constituents are:

Silica	0.7 ppm
Total Hardness (Ca and Mg)	2.0
Bicarbonate	6.0
Chloride	2.0
Sulfate	0.9
Total dissolved solids	10.0

Since only four samples of snow were analyzed, few conclusions can be drawn. Bicarbonate is the most abundant dissolved constituent and comprises approximately 60 percent of the total. High values of chloride and sulfate in the snow might indicate an atmospheric source for the bulk of these constituents in the streams below the snow pack.

Spring Water-Quality

General Chemical Character

The dissolved mineral constituents in spring waters are as much as four times greater when compared with surface waters. Mean values for total dissolved solids and principal mineral constituents are:

Silica	28.4 ppm
Total Hardness (Ca and Mg)	59.0
Bicarbonate	69.0
Sodium	6.1
Sulfate	6.6
Potassium	1.5
Chloride	4.5
Total dissolved solids	143.0

Chemical character of the ground water feeding these springs is probably influenced by additions of water from three sources: water percolating through the soil from precipitation and runoff on the surface, water discharging from bedrock fractures and joints, and water from the stream

percolating through the alluvium and glacial materials. All these additions of water increase the chemical concentrations as a result of longer contact time of these waters with rock materials in the ground-water system. In addition, pH values obtained from the waters are acidic (6.9) which would increase the possibility of a more complete reaction of the water with the geologic materials. Although water-quality values are higher than most surface waters in the area, they are still well under maximum permissable values for consumptive uses. These values indicate that there is probably very little mineralization in the watershed and this would make the ground-water system a possible source for pure water should the area undergo future urbanization.

Suspended Sediments

General Character

Fluvial sediment is generally regarded as that sediment which is transported by, suspended in, or deposited by water. Suspended sediment is that part of the sediment which remains in suspension in water owing to the upward components of turbulent currents or by colloidal suspension. The quantity of this type of sediment, transported or available for transportation, is controlled by climatic conditions, form or nature of precipitation, character of soil mantle, plant cover, topography and land use.

Discussion

From observations made by the writer 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.

Interpretation of Certain Solubilities

It is known that chemical constituents in minerals composing rocks differ widely in their solubility. A full detailed interpretation as to the solubility of all the elements from rocks in the watershed would be beyond the scope of this report; however, certain constituents deserve special note.

Silica

Recent progress in understanding the solubility relations of silica at low temperatures is based on the validity of the silica-molybdate method for the determination of dissolved silica. The soundness of this method has been long questioned because of the uncertainty as to what form or forms of silica responded to it. The work of Iler (1955) has demonstrated beyond question that the colored complex on which the test depends is formed rapidly only by silica

in true solution (monomeric silicic acid, H_4SiO_4) and not a combination of colloidal and ionic silica as was once thought. The silica-molybdate method was employed in this study.

In the waters of the Little South Poudre watershed, silica (in true solution) does not exceed a value of 30 ppm. This interesting characteristic is probably a function of certain equilibrium conditions of silica in the natural water environment. Krauskopf (1959, p. 5) discusses a solubility equilibrium set up between silica in true solution as the monomeric acid and silica in the form of colloidal particles. For comparison, based on both field and laboratory solubility measurements, Krauskopf (1959) found that in the 0° C range the upper limit of dissolved silica would be approximately 50-80 ppm. This concentration is not far from the values obtained in the Little South Poudre with similar temperature conditions.

Presumably, the differences in results between the two values may be referred to differences in the physical state of silica and in the kind of impurities present, but the influence of these and other factors is inadequately known. Although differences exist, the significant facts are that amorphous silica has a definite solubility at certain temperatures (Krauskopf, 1959, p. 6) and the dissolved silica is in true or molecular solution.

Iron

Iron occurs in water at two levels of oxidation, either as bivalent ferrous or as trivalent ferric. In a pH range

of 6 to 8, the amount of ferric iron in solution is theoretically limited by the solubility of ferric hydroxide, about 4×10^{-10} to 5×10^{-6} mg. of iron per liter (Mason, 1952, p. 141), which is below the limit of detection by ordinary laboratory methods. The activity of the microorganisms in dissolving and precipitating iron from water is worth mention as this is the probable cause of the high iron concentration detected in Beaver Creek waters. These organisms may be involved intimately in the processes of oxidation and reduction of iron. In this case certain types of bacteria, existing without oxygen, promoted a highly reducing environment favorable for taking iron into solution in the ferrous state. This could greatly increase the amount of iron in solution in the area and thus produce an anomalous concentration.

ORGANIC QUALITY OF WATER

General Statement

Bacterial analysis is important for detecting sewage and waste contamination in water. Most pathogenic bacteria found in water are indigenous to the intestinal tracts of animals and man; however, minor amounts may be attributed to properties of the soils and to organic decay. Because bacteria of the coliform group are relatively easy to isolate and identify, standard tests to determine their presence or absence in a water sample are taken as a direct indication of the safety of water for drinking purposes. Colifrom tests are reported as the most probable number (MPN) of coliform group organisms in a given volume of water (Todd, 1964, p. 184).

Discussion

In the Little South Poudre drainage, organic quality studies are presently being conducted by the Watershed Management Unit at Colorado State University. Most contamination in the watershed is from animals rather than humans and is concentrated in the Pennock Creek area. Maximum coliform concentrations of 5000 colonies per 100 ml. of sample were recorded by Sam Kunkle (1966, oral communication) during the collection period of April 22 - June 18 in 1965. There is very little human habitation in the watershed, but

several large herds of cattle graze in the area and undoubtedly are adding contaminates to the water. Other tests run by Kunkle (1966, oral communication) indicate maximum values of 500 and 150 colonies per 100 ml. of sample respectively for fecal coliform and streptococcus from the Pennock Creek basin. The stream containing the fewest colonies was Hourglass tributary which drains a portion of Beaver Creek sub-watershed. Minimum colony values dropped as low as zero for both Hourglass and Pennock Creek. Highs were also recorded later in the summer when flows were low and cattle grazing increased.

To evaluate possible contribution from human contamination, Kunkle (1966, oral communication) collected samples above and below campgrounds on the Little South Poudre with negligible results. Qualitatively, from this study, it can be said that presently the human contribution to the organic contamination of water is minimal.

PRECAMBRIAN PETROLOGY OF THE UPPER FALL CREEK AREA

General Statement

The Fall Creek sub-watershed is located in the southwestern section of the Little South Poudre drainage. The upper portion of the sub-watershed is underlain by igneous and metamorphic rocks of Precambrian age which are covered with various Pleistocene and Recent surficial deposits (i.e. glacial, alluvial, and colluvial).

Biotite-quartzo-feldspathic gneiss appears to be the predominant metamorphic rock in the area. Other metamorphic rocks include small bodies of biotite schist and amphibolites. Since a large portion of the metamorphic rocks in the Fall Creek area have very obscure origins that are difficult to evaluate, no conclusive origins can be postulated; however, metamorphic rocks of similar chemical composition and mineral assemblage to the north are thought to have been derived from sedimentary parents (Kirst, 1966).* Most of the metamorphic rocks are a result of almandine-amphibolite conditions of regional metamorphism, although some local retrogression may have occurred. All of the rocks of this group appear to have been subjected to some degree of cataclasis. This is especially true of certain phases of the biotite-quartzo-feldspathic gneiss.

Granite and pegmatite types show little or no effect of metamorphism and are believed to be of a later igneous origin. The major granitic intrusions, which contain predominantly a porphyritic phase with a minor fine-grained variety, occur in the cirque area in the western part of the sub-watershed. Other small bodies of granite and pegmatite occur as dikes and veins cutting across various sections of the country rock.

The rock suite composing the Upper Fall Creek area appears to be representative of the geology of the upper part of the entire Little South Poudre watershed and thus proved invaluable in making geologic-hydrologic interpretations in the water-quality study of the Little South Poudre.

The following descriptions are presented in inferred order from oldest to youngest:

Biotite Schist

General Features

Field relationships suggest that the biotite schist unit is the oldest rock in the area. This unit occurs as sporadic bodies in the biotite-quartzo-feldspathic gneiss on the south side of the sub-watershed (Plate 10). The unit shows a highly developed schistosity, defined by parallel alignment of biotite flakes.

Petrography

The biotite schist is generally fine- to medium-grained and lepidoblastic in texture. Ranges of mineral percentage

in order of decreasing abundance are biotite (58%), quartz (27%), zoisite (?) (8%) and potash feldspar (3%). Plagioclase (An?) is present but only in trace amounts.

Biotite appears remarkably uniform in composition as most pleochroic colors are generally of a light to moderate brown. The biotite typically exhibits strong parallel orientation and sometimes forms tiny microfolds. Metamict zircon halos are also quite common in the biotite.

Some of the biotite grains show moderate to extreme alteration to chlorite (?). Zoisite showing anomalous blue interference color was tenatively identified by the use of immersion oils and optical characteristics. Quartz occurs as fine- to medium-grained crystals in an interlocking mosaic which indicates possible recrystallization. Apatite and opaque minerals are the most abundant accessories; apatite occurs as small euhederal grains, while the opaque minerals are present as discrete grains (predominantly ilmenite and leucoxene with minor amounts of magnetite).

Biotite-Quartzo-Feldspathic Gneiss

General Features

Biotite-quartzo-feldspathic gneiss is one of the major units in the upper Fall Creek area and is quite variable in appearance, texture, and composition. The unit ranges from phases that are finely layered (individual light and dark layers less than ½ cm. wide) to a coarser variety (individual dark layers ½ cm. wide separated by light layers 2-5 cm. wide). Minor folds with fold amplitudes up to 24 cm. are present.

Throughout the sequence occur numerous concordant and discordant tabular bodies and irregular masses of granite, pegmatite and vein-quartz. The intrusion of the large granitic unit has formed a sharp contact with the biotite-quartzo-feldspathic gneiss.

Some cataclasis has occurred in the unit. A few bodies, the largest exposure being four feet long and two feet wide, show moderate to high granulation.

The rock varies in color from pink and white to almost entirely black where biotite is more abundant. Foliation ranges from strong to weak, and is usually defined by the parallel alignment of biotite flakes. Where the foliation is weak, the rock has a granitic appearance.

The gneiss unit is very extensive and covers most of the lower portion and higher topographic divides of the sub-watershed. The unit is well exposed where not covered with surficial deposits and most outcrops show effects of glacial erosion.

Petrography

The different lithologic phases of the biotite-quartzo-feldspathic gneiss complex show some textural variation. Textures range from lepidoblastic and porhyroclastic in the fine- to medium-grained gneisses to cataclastic (intensely crushed and sheared) in the sheared phases. All phases except the sheared phase have a rather high biotite content.

Compositional ranges of the gneissic rock unit are: 27-54% quartz, 17-24% biotite, 6-25% potash feldspar, 5-26%

plagioclase (An_{38-48}), and 1-14% muscovite. Zircon inclusions, some with metamict halos (Plate 4, Figure 1), are common in the biotite. Zones (excluding the sheared phase) of granulated and interlocking quartz grains indicate possible minor shearing and recrystallization. Other effects of minor shearing that are evident throughout the rock are warping of twin lamellae in plagioclase and straining of quartz and feldspar grains (pronounced undulatory extinction).

Many of the feldspar grains in this phase are characterized by partial alteration to fine-grained highly birefringent phyllosilicate minerals; however, some appear to be unaffected. Although the extremely fine-grained alteration products were not analyzed in detail, the secondary minerals in plagioclase are probably a mixture of paragonite and sericite with some larger grains of muscovite. Some of the biotite has undergone alteration to chlorite.

In the intensely sheared phase the composition varies somewhat from the more gneissic phase (Table 6). The rock is characterized by granulation of mineral constituents and presence of moderately developed foliation. The texture is typically cataclastic; however, some portions are granoblastic. Micas and chlorite are typically aligned along zones of maximum shearing (Plate 4, Figure 2). Some feldspar grains are perthitic and exhibit undulatory extinction.

Many of the feldspars paralleling the intensely sheared zones have completely undergone alteration; however, grains in the granoblastic area show little alteration. This may indicate either local retrogression along shear planes or alteration due to an introduction of fluids.

PLATE 4. PHOTOMICROGRAPHS OF BIOTITE-QUARTZO-FELDSPATHIC GNEISS.



Figure 1. Metamict zircon halo in biotite. Sample FC-2, plain polarized light, x 116.



Figure 2. Photomicrograph of intensely sheared biotite-quartzo-feldspathic gneiss. Sample FC-29, crossed nicols, x 40.

Accessory minerals comprise only a very small fraction of the biotite-quartzo-feldspathic gneiss. The predominant opaque minerals present are ilmenite and leucoxene with minor amounts of fine-grained magnetite. Additional accessory minerals are apatite and sphene.

Amphibolite

General Features

The amphibolite occurs sporadically as discontinuous lenses within the biotite-quartzo-feldspathic gneiss, and is more predominant on the north side of the sub-watershed. The largest body is about 100 feet wide and extends for approximately 1000 feet before it is lost beneath a cover of forest "litter" and undergrowth. Other bodies of considerably smaller size (less than 100 feet long and 10 feet wide) were found partially covered with surficial materials making their interrelationships with the surrounding country rock indeterminable.

The amphibolite bodies contain weak to moderate foliation and are dark green to black in color.

Petrography

The rock textures analyzed vary from poikiloblastic to granoblastic. Hornblende is poikiloblastic with inclusions of quartz, feldspar and biotite (Plate 5, Figure 1). The granoblastic amphibolite contains nearly equidimensional grains of hornblende, quartz and plagioclase.

PLATE 5. PHOTOMICROGRAPHS OF AMPHIBOLITE.

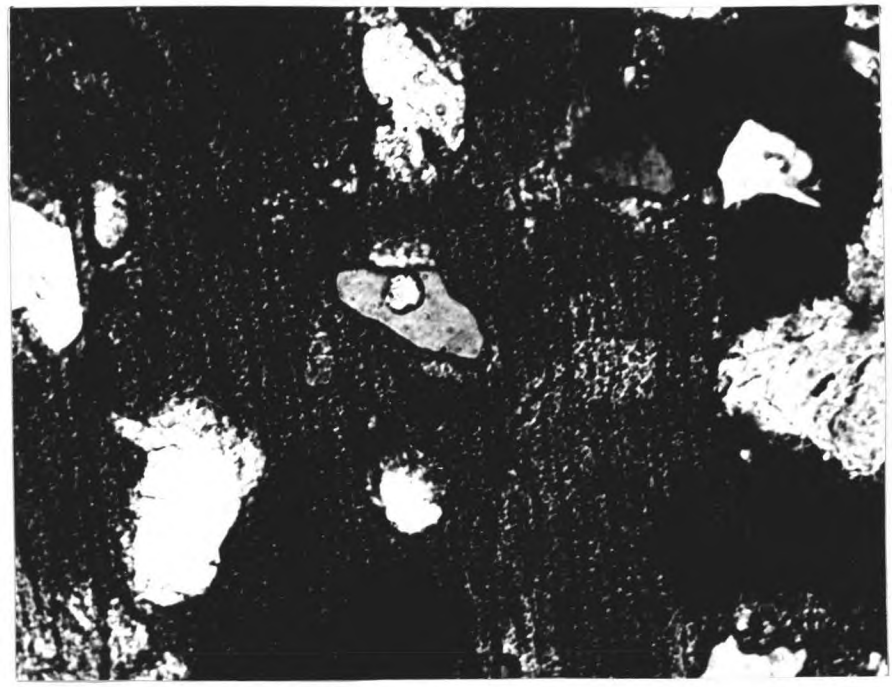


Figure 1. Poikiloblastic texture of an amphibolite. Predominantly hornblende with inclusions of quartz, feldspar and apatite. Sample FC-21, crossed nicols, x 40.

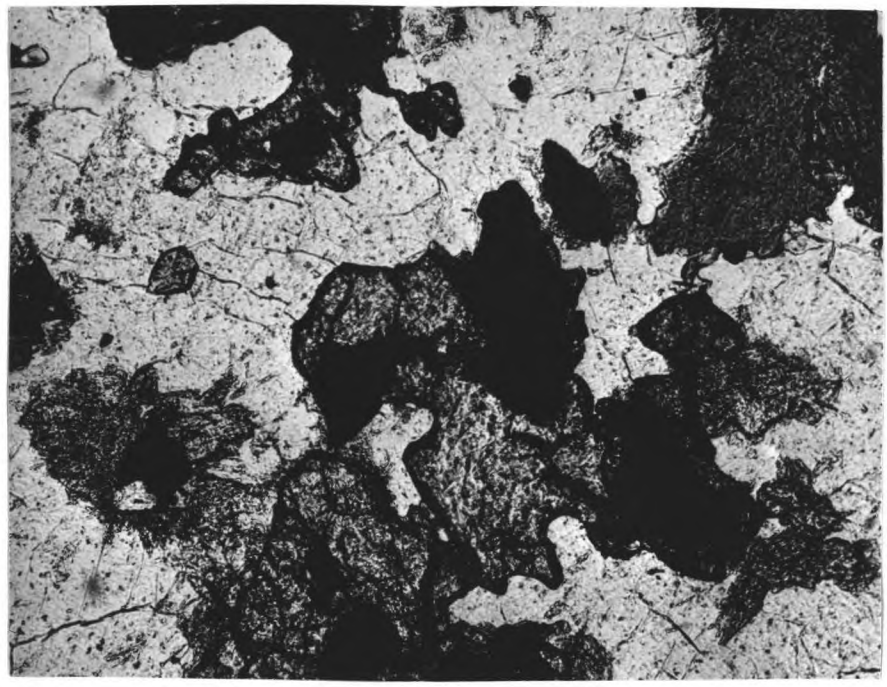


Figure 2. Sphene in amphibolite showing alteration sequence: ilmenite with leucoxene as remnants in sphene. Sample FC-17, plain polarized light, x 116.

The amphibolites contain about 60-75% hornblende, 8-19% plagioclase (An_{55-67}), 4-10% quartz, up to 8% biotite and 1-2% sphene. Calcite is also present in minor amounts and occurs as small veinlets and irregular masses among the hornblende grains.

The hornblende is slightly pleochroic, ranging in color from light brown to dark green. Quartz and feldspar grains are generally xenoblastic, although they do occur as an interlocking mosaic indicating some shearing and recrystallization. Intensity of alteration in the feldspars varies from moderate to high. Another interesting alteration has occurred in the rock with ilmenite altered to leucoxene which has in turn been converted into sphene. Some sphene contains the complete alteration sequence: ilmenite with leucoxene as remnants in sphene (Plate 5, Figure 2).

Moderate to strong foliation is predominant in the finer grained variety and in thin section is exhibited by a layered segregation of hornblende and quartzo-feldspathic grains.

Accessory minerals include ilmenite and leucoxene, with lesser quantities of apatite, sphene, magnetite, and hematite (?).

Granite

General Features

A relatively large body of granitic rock occurs in the cirque area of the Fall Creek sub-watershed. The exact size of this body was not determined, but it is believed to underlie a major portion of the surrounding area. The

contact with the gneissic unit is quite sharp where exposed and was inferred in colluvial areas by the color break between darker gneissic rocks and the lighter colored granitic rocks. Inclusions of gneiss are fairly abundant and some large inclusions (possibly roof pendants) occur in the headwall area of the cirques (Plate 10).

The granitic rock varies from strongly porphyritic with large phenocrysts of potash feldspar (up to 5 or 6 cm. long) to a medium-grained, essentially equigranular, phase. Pegmatitic phases and large quartz veins are also common in some areas, but characteristically occur as extremely small bodies. The rock varies in color from pink to white and contains varying amounts of biotite.

Petrography

Petrographically the granite textures vary from porphyritic, with phenocrysts of potash feldspar (Plate 6, Figure 2), to hypidomorphic-granular. The predominant minerals are potash feldspar and quartz with minor amounts of plagioclase (An_{2-3}) and biotite (Table 6). It is quite common for the quartzo-feldspathic constituents to show undulatory extinction and zones of quartz which appear to have undergone some "crushing". Perthitic development occurs in some of the potash feldspar grains. Alteration of plagioclase and potash is quite characteristic, most grains being partially converted to fine-grained phyllosilicate minerals (sericite ?). It appears that in the porphyritic phase the large phenocrysts are generally less altered than the other feldspar grains making up the matrix.

PLATE 6. OUTCROP AND PHOTOMICROGRAPH OF PORPHYRITIC GRANITE.



Figure 1. Outcrop of porphyritic granite showing large phenocrysts of feldspar.

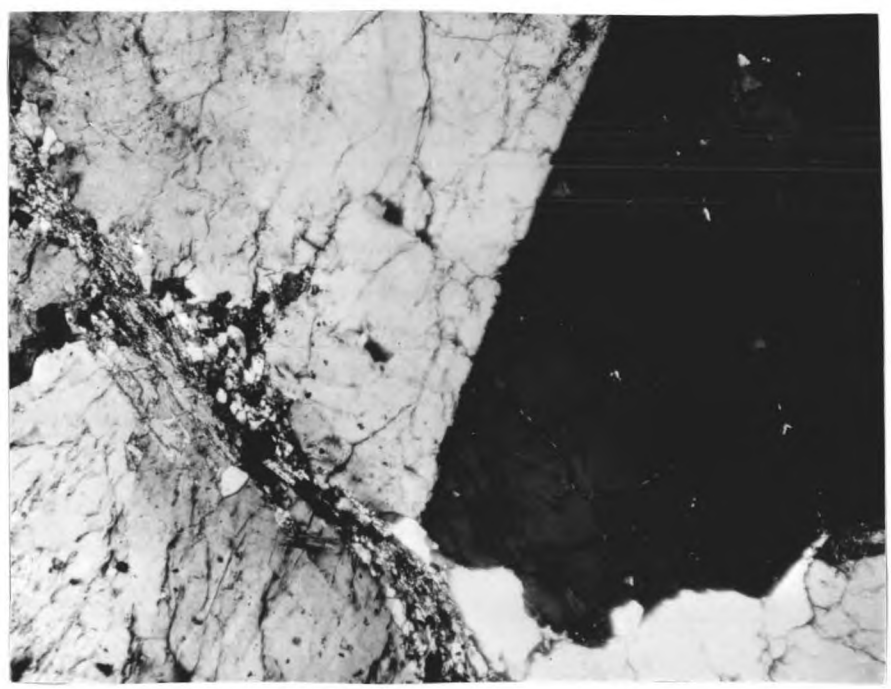


Figure 2. Photomicrograph of porphyritic granite showing Carlsbad twinned phenocryst of potash feldspar. Sample FC-32, crossed nicols, x 40.

Table 6. Modal Analysis (volume percent) of samples representative of the lithologic units of the upper Fall Creek sub-watershed.

Minerals	1 FC-2	FC-11	FC-25	FC-30	FC-29	2 FC-15	3 FC-17	FC-21	4 FC-32	FC-37
Biotite	22	24	17	24	1	58	-	8	9	11
Calcite	-	-	-	-	Tr	-	Tr	-	-	-
Chlorite	1	2	-	-	14(?)	Tr	-	-	-	-
Epidote	-	Tr	Tr	-	Tr	-	Tr	-	-	-
Hornblende	-	-	-	Tr	-	-	60	71	-	-
Muscovite	1	14	12	-	8	1	-	-	-	3
Plagioclase	*$10_{An_{38}}$	*$5_{An_{40}}$	*$7_{An_{44}}$	*$26_{An_{48}}$	*$2_{An_{24}}$	Tr	*$19_{An_{67}}$	*$12_{An_{55}}$	*$20_{An_{2}}$	*$19_{An_{3}}$
Potash Feldspar	14	25	6	20	46	4	5	1	40	34
Quartz	49	28	54	27	28	27	10	4	30	31
Silliminite	1	1	1	-	-	-	-	-	-	-
Zoisite	-	-	-	-	-	7	-	-	-	-
Apatite	-	Tr	-	-	-	1	Tr	Tr	-	-
Hematite	-	-	Tr	-	Tr	-	-	-	Tr	Tr
Ilmenite	1	Tr	1	1	Tr	Tr	2	1	1	Tr
Leucoxene	Tr	-	1	1	Tr	-	1	Tr	Tr	Tr
Magnetite	Tr	Tr	Tr	Tr	Tr	1	1	Tr	Tr	2
Sphene	Tr	Tr	-	-	-	Tr	1	2	-	-
Zircon	Tr	-	Tr	Tr	Tr	-	-	-	-	-

*Presence of saussertized feldspar

1. Biotite-quartzo-feldspathic gneiss (FC-29 sheared body of this unit)
2. Biotite schist
3. Amphibolite
4. Granite

Accessory minerals make up a very small percentage of the bulk composition of the rock (Table 6). Magnetite is the predominant accessory mineral and is randomly distributed throughout the rock section along with minor amounts of hematite.

Origin of the Precambrian Rocks

The metamorphic sequence of biotite schist, biotite-quartzo-feldspathic gneiss and amphibolite probably represents the oldest rocks in the sub-watershed. Although the mapped area was not of sufficient size to develop broad interrelationships of the rocks, it is believed by the writer that they are of sedimentary origin. Rocks of similar composition were studied by Kirst (1966) to the north in the Little South Poudre watershed and he suggests that the metamorphic rocks there were derived from sedimentary parents.

The oldest rock in the area is believed to be the biotite schist. This schist probably represents the metamorphic equivalent of a sequence of pelitic sediments; however, widespread regional metamorphism has obliterated much of the petrographic and field evidence normally used in genetic interpretation. The rocks of this stage of metamorphism apparently represent those of the almandine-amphibolite facies, kyanite-almandine-muscovite subfacies (Turner and Verhoogen, 1960, p. 548).

The biotite-quartzo-feldspathic gneiss unit appears to have gone through an early plutonic stage (either magmatic or granitizing) prior to or in early stages of regional

metamorphism. Evidence is primarily based on the mineralogic composition of the unit which is very high in felsic constituents. Where these felsic constituents are dominant, the unit appears granitic and foliation is very weak. It is doubtful the gneiss could have developed this felsic composition without some reorganization or granitic intrusion. Following this plutonic(?) stage, regional metamorphism attained the grade of sillimanite-almandine-orthoclase subfacies of the almandine-amphibolite facies (Turner and Verhoogen, 1960, p. 544). Some degree of cataclasis occurred during or following this stage attended by development of the sheared zones within the unit.

The small bodies of amphibolite that occur in the biotite-quartzo-feldspathic gneiss appear to be metamorphic equivalents of basic igneous intrusions. Early regional metamorphism of the basic rocks probably converted the original pyroxene to hornblende and imparted a weak foliation to the amphibolitized bodies. Varying degrees of metamorphism are exhibited by this rock group, but most fall in the staurolite-almandine subfacies of the almandine-amphibolite facies.

Mineralogically, the amphibolites studied fit the description given by Turner et al. (1954, p. 241) for those rocks derived from basic igneous materials. In addition to the discordant nature of the bodies (cutting across foliation), petrographic evidence such as the ilmenite-leucoxene-sphene alteration sequence and the poikiloblastic quartz, feldspar and biotite grains in the hornblende may indicate a probable meta-igneous origin (McCallum, 1966, oral communication).

The youngest part of the Precambrian sequence is represented by the granitic rocks in the cirque area. The granite consists of two main textural phases: one phase is porphyritic, with large phenocrysts of potash feldspar whereas the other lacks phenocrysts and is medium- to gine-grained. Field and petrographic evidence, such as numerous inclusions of biotite-quartzo-feldspathic gneiss and greater alteration of the feldspars suggest that the medium- to fine-grained phase is the older. This phase probably represents a stock-like intrusion into the biotite-quartzo-feldspathic gneiss. Although definite contacts were not found, it is believed by the writer that following the intrusion, there occurred a second intrusion or remobilization of the fine-grained type which is represented by the porphyritic phase. The large phenocrysts of potash feldspar were probably formed due to slower cooling which would induce development of larger crystals. Evidence for this second intrusion in addition to certain field relationships includes the absence of inclusions of biotite-quartzo-feldspathic gneiss and the lack of intensive alteration of the feldspars.

Plutonic intrusions are common in the Front Range. Studies by Lovering and Goddard (1950) and Tweto (1966) indicate that most large granite bodies were emplaced by forceful intrusion of magma. The evidence in the study area suggests that the granites present are post-metamorphic plutonic intrusions.

Structure

Foliations

Most of the rocks in the area have rather pronounced foliation, although in several phases of the biotite-quartzo-feldspathic gneiss foliation is rather inconspicuous. Foliation is primarily developed by the alignment of biotite, muscovite and amphibole.

Strikes of foliation throughout the mapped area range approximately from N. 65° E. to N. 85° E. Dips are generally steep to vertical.

Lineations

Few lineations were observed and; therefore, very little interpretation can be made. The lineations recorded were those defined by plunge axes of the minor folds.

Folds

No major fold structures were recognized in the area. Minor folds and crenulations do exist, but no major structural trends were indicated.

POST-PRECAMBRIAN DEPOSITS

Glacial Deposits

General Statement

Glacial deposits in the Fall Creek sub-watershed suggest that the area has been subjected to several episodes of glaciation. The deposits all appear to be products of late Pleistocene (Wisconsin) to Recent glaciations and most of them have been correlated by the writer with similar glacial deposits described by Richmond (1960) in nearby Rocky Mountain National Park. Probable glacial chronology in the area is listed in Table 7. Distinctions between deposits of the different glaciations in the Fall Creek basin is made on the basis of their topographic, stratigraphic, and weathering characteristics, and correlation with glaciations in the National Park is based on comparison of these characteristics. The deposits in both areas are primarily derived from Precambrian crystalline rocks.

Bull Lake (?) Glaciation

No definite evidence of Bull Lake glaciation was found in the Fall Creek area; however, several "bowl"-like areas which occur on the north and south sides of the valley may be remnants of cirques occupied by Bull Lake glaciers. Bull

Table 7. Correlation of nomenclature of moraines and glacial events in upper Fall Creek sub-watershed with those used in Rocky Mountain Park, Colorado, and Wind River Mountains, Wyoming.

		Blackwelder (1915) (Wind River Mts.)	Richmond (1960) (Rocky Mts.)	Mercer this Paper
RECENT	Neoglaciation	Gannet Peak Stade Spanish Valley	Historic Stade	Gannet Peak Stade
		Temple Lake Stade Castle Valley	Temple Lake Stade	Temple Lake Stade
LATE PLEISTOCENE	Pinedale glaciation	Late Pinedale Stade Pack Creek	Late Stade	Pinedale Stade (undifferentiated)
			Middle Stade	
		Early Pinedale Stade Lackey Creek	Early Stade	
	Bull Lake glaciation	Late Bull Lake Stade Porcupine Ranch	Late Stade	Bull Lake Stade (?) (undifferentiated)
		Early Bull Lake Stade	Early Stade	

Lake (?) deposits have been reported further to the north in the Big Beaver drainage by McCallum (1966, oral communication).

Pinedale (?) Glaciation

Morainal deposits of Pinedale (?) glaciation cover a major portion of the study area. At least two advances have occurred in the area below the cirques. Although not differentiated on the map (Plate 10), they are represented by patches of several lateral moraines visible along the valley sides above Cirque Meadows. A dissected terminal moraine of one of the Pinedale (?) advances occurs near the gaging station.

Apparently the several Pinedale (?) advances that occupied the sub-watershed were responsible for the development of the cirques that now form one of the most prominent topographic features in the study area. These cirques, one on the south and a composite cirque on the north, are referred to as Fall Mountain Cirque and Emmaline Lake Cirque, respectively.

In the Fall Mountain Cirque a terminal moraine dissected by later outwash channels was observed at the mouth proper, and probably represents the latest Pinedale (?) advance (Plate 7, Figure 1). This moraine is characterized by a youthful soil and vegetational development and is covered with fresh boulders.

PLATE 7. POST-PRECAMBRIAN DEPOSITS; LATEST PINEDALE (?) ADVANCE



Figure 1. Exposure of dissected Pinedale (?) terminal moraine, Fall Mountain Cirque.

Temple Lake (?) - Gannet Peak (?) Glaciation

In the upper portion of Fall Mountain Cirque there are several small terminal moraines that indicate two minor advances of Recent glaciation. The outer deposits probably represent products of the Temple Lake (?) stade, whereas, the inner deposits have the fresh aspect so characteristic of the Gannet Peak stade. The Temple Lake (?) terminal moraine is covered with fresh boulders and small patches of vegetation; soil development is minimal (Plate 8, Figures 1 and 2). The Gannet Peak (?) terminal moraine is smaller in extent than the Temple Lake (?) moraine and is also covered with fresh boulders, but has very weak soil development (Plate 9, Figure 1).

It is interesting to note that these terminal moraines occur in pairs (Plate 10) that are similar in extent and elevation. Evidently the glaciers were not large enough to cover the cirque floors and these pairs of moraines represent separate advances out of the same cirque.

Similar occurrences must have occurred in the Emmaline Lake Cirque; however, moraines, if present, either have been covered with colluvial materials or are represented by the rock glaciers (?) that are present in the cirques (Plate 9, Figure 2).

Recent Alluvial and Colluvial Deposits

Small areas of recent alluvium and colluvial debris are scattered throughout the area. Most of these deposits are intermixed making subdivision impractical.

PLATE 8. POST-PRECAMBRIAN DEPOSITS; TEMPLE LAKE (?) STADE TERMINAL MORAINE.



Figure 1. Temple Lake (?) terminal moraine covered with fresh boulders and small patches of vegetation.



Figure 2. Soil development on crest of Temple Lake (?) moraine, scale is shown by six inch ruler (location of soil sample site indicated by arrow, Figure 1).

PLATE 9. POST-PRECAMBRIAN DEPOSITS; GANNET PEAK (?) STADE TERMINAL MORAINE AND RECENT ROCK GLACIER (?).



Figure 1. Gannet Peak (?) terminal showing fresh boulder surface and lack of soil development.



Figure 2. Rock glacier (?) development in the Emmaline Lake Cirque.

Colluvial deposits cover major portions of the headward regions and are best developed in areas of high relief along mountain fronts. Included in the colluvial deposits are talus and "rock glacier" debris in Emmaline Cirque.

Alluvium consists of stream-associated soils, clays, and gravels, which may be observed along Fall Creek which drains the area. This material is to a large extent re-worked glacial material.

SUMMARY AND CONCLUSIONS

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 on chemical elements in the rocks, producing 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) 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.

7) 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.

8) 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.

9) 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 downstream 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.

PROBLEMS NEEDING ADDITIONAL INVESTIGATION

1) Seriously needed are investigations into field methods of chemical analyses for detecting concentrations of chemical constituents in waters very low in total dissolved solids.

2) Geologic studies as related to hydrology should be conducted in the watershed since the area is covered with glacial materials which must have an effect on inorganic quality of water.

3) Future investigations of inorganic quality of water should be expanded to include experimental determinations of rock and mineral solubilities.

4) In order to study the relative mobility of the common elements in water (ratio of the percentage of element in water to the percentage of element in the rock), chemical analyses of representative rock samples should be carried out.

5) For geologic studies, detailed mapping of the Precambrian crystallines should be conducted and absolute ages of some of the rock units should be obtained for purposes of correlation.

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APPENDIX

Table 8. - Chemical Constituents in Surface Waters Draining the Little South Poudre Watershed

(Results in parts per million unless otherwise indicated)

Sample Number 1/	Date Sampled (1965)	Silica (SiO_2)	Iron (Fe) 2/	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Aluminum (Al)	Copper (Cu)	Heavy 3/ Metals	Dissolved Solids 4/	pH	Temp. (°C)
Surface Waters of the Little South Poudre Sub-Watershed (July-August 1965) 6/																			
LS-46	8/12	19.0	Tr	2	3	.8	.5	12	1	2.5	.21	.02	--	.03	.12	--	35	7.4	7.0
LS-57	9/1	17.6	Tr	6	1	.9	.5	9	1	1.5	.30	.25	--	.03	.12	2	34	7.2	6.0
LS-56	9/1	22.6	Tr	4	6	.7	.5	10	3	2.0	.28	.20	--	.04	.10	2	44	7.4	7.0
LS-55	9/1	17.6	Tr	7	1	.6	.4	11	2	2.5	.35	.20	--	.05	.10	2	38	7.7	7.0
LS-53	8/21	15.6	.10	4	2	.8	.5	14	2	1.0	.35	.10	--	.02	.13	10	34	7.5	9.5
LS-47	8/13	14.0	.10	2	5	.8	.7	11	1	2.0	.30	.10	--	.04	.09	2	32	7.8	9.0
LS-4	7/9	17.4	.25	6	3	.8	.6	18	2	3.0	.31	Tr	--	.01	.06	2	42	7.0	7.0
LS-2	7/9	16.9	.16	6	2	.8	.4	21	3	4.5	.32	--	Tr	.02	.06	--	45	7.0	7.0
LS-29	7/27	10.3	.05	5	4	.8	.6	13	Tr	3.0	.30	.30	--	.01	.10	10	31	7.5	13.0
LS-6	7/9	18.4	.10	4	9	.8	.5	12	5	3.5	.30	Tr	--	.01	.09	2	48	7.2	9.5
LS-23	7/22	8.9	.15	6	1	.7	.6	14	2	2.0	.10	.10	--	Tr	.06	2	30	7.3	10.0
LS-24	7/22	8.9	.15	6	2	.9	.8	13	3	2.0	.10	--	--	.01	.04	2	31	7.1	11.0
LS-22	7/21	8.4	.11	5	3	.7	.6	12	1	2.5	.20	.10	--	.02	.12	10	28	7.2	10.5
LS-8	7/9	14.8	.20	5	4	.8	.6	12	5	2.0	.35	.10	--	.02	.08	2	39	7.3	9.5
LS-21	7/21	9.4	.20	5	5	.9	.6	16	1	3.0	.21	Tr	--	.03	.09	10	33	7.4	11.0
LS-13	7/16	16.8	.10	4	5	.9	.6	14	3	2.0	.29	--	--	.01	.10	10	40	7.1	9.0
LS-17	7/19	16.0	.05	2	8	.8	.5	16	2	3.5	.20	--	Tr	.03	.05	15	41	7.5	12.0
LS-19	7/19	10.4	.10	3	6	.9	.6	15	3	2.5	.15	--	.03	.02	.03	10	35	7.3	13.0
LS-10	7/9	15.8	.20	3	5	1.0	.6	16	3	2.5	.30	Tr	--	.03	.05	10	40	6.9	9.5
(December 1965)																			
LS-66 (47) 5/	12/5	15.6	.12	4	6	.9	.6	15	3	2.5	.43	.30	Tr	.03	.03	2	42	7.2	3.0
LS-65 (4)	12/5	16.6	.18	7	3	1.0	.6	13	3	3.5	.40	.12	Tr	Tr	Tr	2	42	7.2	2.0
LS-73 (24)	12/17	18.6	.11	10	10	1.0	.6	21	2	3.0	.38	Tr	--	.02	.07	--	67	7.2	1.0
LS-74 (23)	12/17	17.6	.10	9	2	1.1	.7	20	2	3.5	.28	.20	--	.04	.08		47	7.4	2.0
LS-76 (8)	12/17	18.6	.08	10	8	.9	.6	23	3	2.5	.35	.32	--	.04	.10		57	7.4	0.0
LS-79 (21)	12/17	19.6	.09	11	8	1.2	.7	24	3	3.5	.32	--	.02	.01	.05		60	7.2	0.0
LS-70 (10)	12/5	20.6	.04	9	2	1.0	.7	25	2	2.5	.30	Tr	Tr	.05	.05		51	7.2	0.0
Surface Waters of the Fall Creek Sub-Watershed (July-August 1965)																			
FC-34	8/4	12.0	.02	6	1	.4	.2	11	1	4.5	.28	.10	--	.03	.08	2	32	7.8	5.5
FC-36	8/4	12.0	Tr	2	2	.3	.2	8	2	4.0	.32	.20	--	.04	.05	2	28	7.8	9.5
FC-45	8/11	14.0	.02	2	5	.6	.3	11	Tr	2.5	.18	.03	Tr	.02	.08	2	31	7.7	8.5
FC-20	7/21	15.9	.05	4	4	.5	.3	13	1	2.0	.11	.10	--	.02	.05	2	35	7.4	7.5
FC-58	9/1	14.6	Tr	2	3	.7	.3	13	3	1.5	.30	.50	--	.04	.08	5	38	7.5	8.5
Surface Waters of the Pennock Creek Sub-Watershed (July-August 1965)																			
PC-27	7/27	15.3	.04	9	3	.8	.5	14	2	1.5	.40	Tr	--	.01	.06	2	40	7.4	8.5
PC-26	7/27	18.3	.10	6	3	1.3	.8	19	2	4.0	.30	.40	--	.02	.12	2	46	7.2	8.5
PC-60	9/1	12.6	Tr	3	9	.8	.5	10	2	1.0	.22	.20	--	.01	.05	2	34	7.2	9.5
PC-59	9/1	13.5	.01	4	5	1.0	.4	8	1	2.0	.27	Tr	Tr	.02	.01	2	31	7.4	9.0
PC-52	8/21	24.6	.05	8	2	1.0	.6	15	2	2.5	.20	.15	--	.05	.10	10	49	7.6	10.5
PC-54	8/21	23.6	.20	8	3	1.1	.7	21	5	2.0	.22	.80	--	.03	.10	2	53	7.3	9.0
PC-7	7/9	24.4	.20	4	8	1.4	.8	21	7	2.5	.30	.80	--	.02	.03	2	45	7.3	8.5
(December 1965)																			
PC-68 (27)	12/5	23.6	.03	2	6	.9	.5	21	4	3.0	.40	.10	Tr	.02	.06		52	7.3	1.5
PC-71 (52)	12/17	25.6	Tr	8	4	.9	.7	13	4	3.5	.28	.20	--	.04	.06		54	7.1	0.0
PC-72 (54)	12/17	29.6	.18	8	9	1.3	.7	25	3	3.0	.40	.20	.10	.03	.09		69	7.2	0.0
PC-69 (7)	12/5	24.6	.07	8	4	1.5	.8	21	3	2.0	.30	--	--	.08	.03		55	7.2	1.0
Surface Waters of the Beaver Creek Sub-Watershed (July-August 1965)																			
BB-37	8/10	14.0	.03	2	3	.7	.4	11	1	2.0	.30	.10	--	--	.10	5	30	7.8	7.5
BB-38	8/10	20.4	.03	7	1	.8	.5	12	2	1.5	.20	.20	--	.02	.06	10	40	7.9	7.5
BB-39	8/10	23.4	.06	5	3	.6	.4	18	3	3.0	.20	.30	--	.06	.10	10	48	7.8	13.0

Table 8. - Surface Waters of the Little South Poudre - continued

Sample Number	Date Sampled (1965)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Aluminum (Al)	Copper (Cu)	Heavy Metals	Dissolved Solids	pH	Temp. (°C)
Beaver Creek Sub-Watershed - continued																			
BB-40	8/10	20.4	.08	5	0	.8	.5	13	3	2.5	.15	.10	--	.03	.09	10	40	7.9	9.0
BB-41	8/10	27.4	.02	6	5	.5	.4	19	4	2.5	.25	Tr	Tr	.06	.09	10	56	7.4	8.5
BB-42	8/10	20.4	.30	6	4	1.0	.7	14	3	2.0	.20	.10	--	.06	.08	2	45	7.7	12.0
BB-43	8/10	20.6	.10	3	6	1.9	1.3	17	5	2.5	.22	.20	--	.05	.07	10	53	7.4	13.0
BB-3	7/9	19.4	.11	4	5	.8	.5	14	2	3.0	.23	.10	--	.02	.08	10	42	7.1	9.5
(December 1965)																			
BB-62a (42)	12/5	16.6	.35	7	8	1.0	.5	20	4	3.0	.20	Tr	Tr	.01	.05	10	51	7.1	4.5
BB-62b	12/5	18.6	3.00	8	3	1.0	.7	10	2	2.5	.22	.10	Tr	.05	.04	10	44	7.0	9.0
BB-63 (43)	12/5	16.7	.08	5	1	1.0	.8	18	4	2.0	.28	--	--	.01	.05	5	41	7.3	2.0
BB-64 (44)	12/5	18.6	.07	7	4	1.2	.8	19	5	3.5	.25	.10	--	.01	.10	5	51	7.4	3.0
Surface Waters of the Fish Creek Sub-Watershed (July-August 1965)																			
FK-30	7/27	17.3	.30	11	7	1.5	1.0	25	4	2.5	.30	.60	--	.02	.05	10	59	7.5	8.0
FK-28	7/27	17.8	.05	16	7	2.0	1.0	33	1	3.0	.30	.30	Tr	.05	.10	2	66	7.2	9.5
(December 1965)																			
FK-84 (28)	12/17	24.6	.10	18	10	3.2	1.7	41	2	3.0	.20	.50	--	.03	.07	10	85	7.2	0.0
Surface Waters of the Little Beaver Creek Sub-Watershed (July-August 1965)																			
LB-31	7/29	15.2	.03	4	4	1.0	.5	17	2	4.0	.20	.40	Tr	.01	.04	2	41	7.2	7.0
LB-32	7/29	21.0	.10	5	3	1.0	.6	19	2	2.0	.30	.20	--	.03	.06	2	45	7.1	10.5
LB-33	7/29	20.0	.11	8	1	.9	.7	21	2	4.0	.30	.30	Tr	.02	.09	--	49	7.2	12.5
LB-9	7/9	18.8	.21	5	4	1.3	.8	20	2	3.5	.27	.80	--	.03	.09	10	47	7.5	10.0
(December 1965)																			
LB-80 (33)	12/17	18.6	.06	5	3	1.2	.7	22	3	2.5	.29	--	--	.10	.11	5	46	7.1	0.0
LB-77 (9)	12/17	19.6	.08	8	4	1.5	.8	24	2	3.5	.25	.10	--	.06	.09	5	52	7.3	0.0
Surface Waters of the Pendergrass Creek Sub-Watershed (July-August 1965)																			
PK-18	7/19	10.4	.08	21	9	3.8	1.3	30	6	3.0	.23	--	--	.02	.05	20	75	8.0	13.0
Minor Tributaries																			
Twin Lakes Tributary (July-August 1965)																			
TW-1	7/9	28.4	.42	10	14	2.5	1.0	32	5	3.5	.60	.20	--	.03	.07	--	82	7.4	9.0
TW-15	7/16	19.0	.15	7	4	.9	.6	17	5	2.5	.38	.60	--	.01	.09	--	45	7.2	9.5
Hourglass Tributary (July-August 1965)																			
HG-16	7/16	18.4	.05	2	7	.8	.5	11	--	2.5	.22	--	--	.03	.11	2	38	7.-	6.5
(December 1965)																			
HG-61 (16)	12/5	19.6	.05	5	6	1.0	.5	15	1	2.0	.30	Tr	--	.02	.10	--	44	7.0	-.5

1/ For explanation of location numbering system see Plate No. 3
2/ Field Analysis (Ferrous ion)
3/ Field analysis using the dithizone dye method reported in parts per billion
4/ Total dissolved solids expressed as the sum of ppm of constituent ions
5/ Where resampling of the same location occurred, previous sample number is given in parenthesis
6/ Analyses of all streams arranged in order from headwaters to mouth

Table 9. - Chemical Constituents in Spring Waters and Snow Samples of the Little South Poudre Watershed*

(Results in parts per million unless otherwise indicated)

Sample Number	Date Sampled (1965)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Aluminum (Al)	Copper (Cu)	Heavy Metals	Dissolved Solids	pH	Temp. (°C)
Spring Waters (July-August 1965)																			
SP-12	7/16	28.2	3.00	65	27	7.5	2.0	91	10	5.0	.45	.40	--	.05	1.50	40	196	8.1	9.5
SP-11	7/16	32.8	.20	41	16	9.0	1.8	71	8	4.0	.50	Tr	Tr	.04	.08	10	148	6.5	9.0
SP-14	8/13	28.2	.10	28	11	1.3	.8	54	3	5.0	.35	.70	Tr	.04	.10	2	106	6.9	9.0
SP-48	8/13	24.0	.02	53	10	8.5	2.0	82	8	4.5	.22	.08	Tr	.02	.03	2	151	6.9	8.0
SP-51	8/21	29.0	.40	40	5	4.3	1.0	47	4	4.0	.20	.60	--	.05	.16	2	113	6.8	9.0
(December 1965)																			
SP-67	12/5	29.6	.02	18	14	4.4	1.2	38	2	4.0	.90	.40	--	.01	.04	2	94	6.7	3.0
SP-78 (48)	12/17	22.6	.05	55	20	6.5	2.0	91	5	6.0	.30	Tr	Tr	.01	.12	2	164	6.8	5.0
SP-81 (51)	12/17	26.6	.08	45	7	4.9	2.1	48	2	4.0	.25	.20	--	.03	.02	5	116	7.3	1.0
Snow Samples (July-August 1965)																			
SN-35a	8/4	.4	--	1	--	.2	.1	9	--	3.0	.28	.10	--	.01	--	--	11	--	--
SN-35b	8/4	.9	Tr	3	--	--	--	7	1	2.5	.10	.20	--	Tr	--	--	12	--	--
SN-35c	8/4	1.0	--	2	1	.2	.2	5	1	2.0	--	--	--	--	--	--	10	--	--
SN-35d	8/4	.6	Tr	1	--	--	--	2	1	.5	.15	.11	--	.02	--	--	5	--	--

*Same explanations apply to Table 9 as are used in Table 8

FIELD METHOD FOR TOTAL HEAVY METALS IN WATER

The principle of this water testing method depends on (1) the conditioning of heavy metals by adjusting pH and adding water conditioning solution; and (2) the extraction of the metals by extracting dye solution in the form of metal-dye compounds. Each metal-dye compound has a specific color. Procedure is adapted from Lakin, Almond, and Ward (1959), Mukherjee and Anthony (1957), and Huff (1948).

1. Preparation of Testing Reagents

   A. Metal Free Water

      1. Collect the low-heavy-metal content water (distilled water in the polyethylene squirt bottle demineralizer.
      2. Invert the bottle and squeeze it to force out metal-free water as needed.

   B. Water Conditioning Solution

      The water conditioning solution can be prepared and carried to the field.

      1. Direction for Preparation:
         a. Add approximately 15 gm of sodium acetate in a 500-ml separatory funnel.
         b. Pour into the separatory funnel 90 ml of metal-free water.
         c. Shake it to dissolve all sodium acetate.
         d. Place 10 ml of metal-free water in the 100-ml cylinder and add 1 ml of glacial acetic acid until 11-ml mark is reached. Shake well.
         e. Pour the glacial acetic acid solution from the cylinder into the separatory funnel and add small amounts (4 or 5 ml) of concentrated dithizone solution (see below). Shake well. If the green color of the dye solution changes to another color, it indicates the presence of impurities.
         f. Let the solutions in the funnel settle.
         g. Drain off the dye solution layer.
         h. Continue Steps e to g until the dye solution remains the same shade of original green.

i. Transfer the conditioning solution from the separatory funnel to 8-oz poly bottle with the welded straight cone tip.

C. pH Adjusters

1. Direction for Preparation:
   a. Acidic pH adjuster: Place about 20 ml of metal-free water in a 2-oz dropping bottle and then add about 10 ml of concentrated hydrochloric acid. Shake well.
   b. Basic pH adjuster: Place about 15 ml of concentrated ammonium hydroxide in a 2-oz dropping bottle and then add about 15 ml of metal-free water. Shake well.

D. Concentrated Dye Solution (0.01% dye solution) in Carbon Tetrachloride (for further dilution)

1. Direction for Preparation:
   a. Weigh exactly 0.01 gram of dithizone (dye) in a clean tiny vial with plastic cap.
   b. When ready for testing, add 0.01 gram of dithizone from the vial to a clean, dry, 100-ml cylinder.
   c. Add about 50 ml of pure carbon tetrachloride. The dye gives a dark green color in the solvent. Wash the tiny vial with pure carbon tetrachloride several times to remove the last traces of the dye from the vial. Fill the cylinder to the 100-ml mark.
   d. Place this dye solution in a clean 8-oz poly bottle, lable, and store in a cool, dark place.

E. Extracting Dye (Dilute) Solution (0.001% dye solution) in Carbon Tetrachloride (for water testing).

This solution should be prepared from the concentrated dye (dithizone) solution in carbon tetrachloride just before use. The dilution is 10 times.

2. Testing Procedure for Collected Samples

All equipment and reagents should be metal-free. If not, all equipment should be cleaned with the extracting dye solution (part E above). The step by step testing procedure is given below:

A. Wash the 100-ml cylinder several times with water to be tested.
B. Collect 50-ml of clear water.
C. Check the pH of water with pHydrion paper. pH of water sample should be 5½. If it is not, adjust it by using acid or basic pH adjusters.
D. Add one good squirt of water conditioning solution (about 5 drops).
E. Pour exactly 5 ml of extracting dye solution (0.001%) into cylinder.
F. Shake vigorously for one minute and allow the dye solution to settle.
G. If the green color of the dye changes to light green or other colors, take the reading in terms of parts of heavy metals in billion parts of water (ppb) as follows:

Color Inidcation for Water Prospecting

Color	ppb	Color	ppb
Orig. shade of green	0	Pale violet	80
Light green	10	Light violet with a touch of red	100
Light green with a touch of blue	20	Light red with a touch of violet	300
Light blue with a touch of green	40	Red	over 400

H. If the dye layer is a shade lighter than the original green at the end of the above Step F, perform the following test, called "monocolor test".
Add drop by drop the basic adjuster until the pH is 9 (usually 2 drops are enough). Shake vigorously for 15 seconds, and allow the dye layer to settle. Read the color of the dye layer as follows:

Monocolor Indication in Water Prospecting

Color	ppb	Color	ppb
Colorless	0	Light pink	10
Faint Pink	2	Strong pink	20

Identification of Heavy Metals

pH	Color	Metal
5½	Pink	Zinc
5½	Violet or red	Lead or others
3	Violet or yellow-brown	Copper

Table 10. Discharge Data for July-August 1965 from the Little South Poudre (mainstem) and selected tributaries (CSU-Cooperative Watershed Unit Records).

		Location**						
		A			B	C	D	E
		1	2	3				
July	1	110*	369	415	47	142	43	42
	9	91	257	?	34	132	31	32
	16	68	238	255	17	76	32	21
	22	72	212	288	16	57	22	21
	30	50	166	176	10	42	?	17
August	5	41	121	129	8	31	14	11
	10	29	126	133	7	24	?	9
	19	29	164	170	6	65	14	6
	26	19	77	81	5	16	12	3

*All flow values in cfs.
**Location

A. Little South Poudre (mainstem)

1) Pingree Park Station

2) Fish Creek Camp Ground Station

3) Quigley Mountain Station

B. Little Beaver Creek

C. Beaver Creek

D. Fall Creek

E. Hourglass Creek

Table 11. Surface area, stream gradient, stream length, and drainage density of the sub-watersheds of the Little South Poudre.

Sub-watershed	Area sq.mi.	Stream gradient %	Stream length mi.	Drainage density
Little Beaver Creek	18.11	7.5	12.2	0.67
Fish Creek	6.60	7.9	5.6	0.85
Beaver Creek	22.27	5.3	15.1	0.68
Fall Creek	4.31	10.6	4.8	1.14
Little South Poudre (main)	30.93	5.0	20.2	1.08
(trib.)			13.1	
Pennock Creek	17.55	6.5	10.4	0.59
Pendergrass Creek	5.16	10.8	7.0	1.36

(From Johnson et. al., 1963)

$$\text{Stream gradient} = \frac{\text{head to mouth relief}}{\text{distance}}$$

$$\text{Drainage density} = \frac{\text{stream length}}{\text{surface area}}$$

EXPLANATION

SYMBOLS

- LAKES
- BASIN DIVIDE
- CONTACT
- PROBABLE CONTACT
- UNKNOWN CONTACT
- KH — KETTLE HOLES
- BOULDER FIELDS
- MORAINAL RIDGES PINEDALE 1B/or2

GEOLOGIC UNITS

RECENT	Qal — ALLUVIUM	
	G — GANNETT PEAK STADE	SCREE — SCREE
	T — TEMPLE LAKE STADE	COLLUVIUM, SLIDE DEBRIS W/ SCATTERED OUTCROP
PLEISTOCENE	Pm3 — PINEDALE 3 STADE	OUTWASH OVER PINEDALE 2
	Pm2 — PINEDALE 2 STADE	OUTWASH OVER PINEDALE 1r
	Pm1r — PINEDALE 1 RECESSIONAL STADE	OUTWASH OVER PINEDALE 1
	Pm1 — PINEDALE 1 STADE	OUTWASH OVER Pc
	BL — BULL LAKE (UNDIFFERENTIATED)	
PRECAMBRIAN	Pc — PRECAMBRIAN METAMORPHIC AND IGNEOUS ROCKS	

PLATE 2



GEOLOGIC MAP

SURFICIAL GEOLOGY
by L.A. CERRILLO

BEAVER CREEK BASIN

LARIMER COUNTY
COLORADO

L.A. CERRILLO
JUNE, 1967

