Geochemical Baselines of Stream and Spring Waters From Areas Underlain by Permian and Pennsylvanian Rocks, Including Evaporites, and Potential Environmental Damage in the Eagle Valley, Colorado

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Introduction

When precipitation, as rain and snow, falls within a watershed, water comes into contact with rock minerals and chemical weathering is initiated. These processes release elements to the natural waters of a watershed. Therefore the chemical composition of natural waters that evolve within a watershed, in the absence anthropogenic input, is determined mostly by the chemical composition of rocks within the basin. Other factors such as rates of mechanical erosion, grain size and crystallinity of the rock minerals, amount and distribution of precipitation, temperature, type and amount of vegetation, and biota activity influence mainly the rates of the water-rock reactions, but the chemical composition of the rocks is the fundamental factor which determines the type of waters which evolve within a headwater watershed (Miller, 1999). This natural baseline geochemistry of waters of a watershed can be modified by input from anthropogenic processes which are always superimposed on the background geochemistry. The distribution of water available in streams and springs in these headwater watersheds is uneven throughout the year in western Colorado with high flows during the spring runoff and after summer thunderstorms. In the winter, water available in streams and springs reaches a minimum when element concentrations are high but mass flux is low. At this time, runoff is fed mainly by the recession of the groundwater reservoir. Geochemical baselines, at a particular point in time, can be determined for stream and spring waters in these headwater watersheds, and may approximate the background geochemistry. Because water geochemistry is sensitive to changes in the environment, by monitoring water geochemistry in these watersheds and comparing the results to the earlier geochemical baseline data, changes within the watershed can be detected.

The purpose of this study is to determine the baseline range of species and other geochemical parameters in order to characterize the baseline geochemistry of stream and spring waters evolving within headwater watersheds underlain by Permian and Pennsylvanian rocks which occur in western Colorado and often contain highly soluble evaporite minerals. Processes responsible for the control and mobility of species in the natural waters were also investigated as well as potential environmental damage associated with development of golf courses, homes, and ski areas on the Evaporite Facies rocks in Eagle Valley.

Study Area

The study areas occur within western Colorado (fig. 1) in the Southern Rocky Mountain physiographic province (Hunt, 1974). The mountain ranges and intermountain basins generally trend north-northwest. Dendritic drainage patterns are well developed and most of the area is of moderate to high relief. Several peaks are above 14,000 feet and the lowest point is around 6,500 feet along the Arkansas River. Annual precipitation ranges from as little as 10 inches near Antereo Reservoir in South Park to more than 40 inches in the higher Flat Tops area (Colorado Climate Center, 1984). Snow-melt runoff usually occurs from April through July and peaks in May through June (Apodaca and others, 1996).

Because of the large differences in altitude, the climate in the study area varies from cool-humid in the higher mountains to semi-arid in the lower elevations. The natural vegetation in the study area is strongly zoned by altitude. The vegetation in the subalpine zone is dominated by spruce and fir, the montane zone by pine and Douglas fir, which can alternate with juniper-pinyon woodland, and mountain mahogany - scrub oak. Unforested mountain parks dominated by grasses and sometimes sagebrush and other shrubs are also present (U.S. Dept. of Agriculture, 1972).

Geological History of the Permian and Pennsylvanian Rocks

Permian and Pennsylvanian rocks in Colorado were formed during a series of continental collisions that resulted in deformation and uplift. The Ancestral Rocky Mountains formed around 300 mya probably as the result of the collision of North America with South America-Africa along the southern margin of North America (Curtis, 1958). Tectonic activities consisted of block-fault mountain uplifts and subsiding basins between the uplifts. The Ancestral Rocky Mountains formed along two belts. The eastern belt is known as the ancestral Front Range uplift and the western belt as the Uncompahgre uplift. During the early stages of tectonic activities,

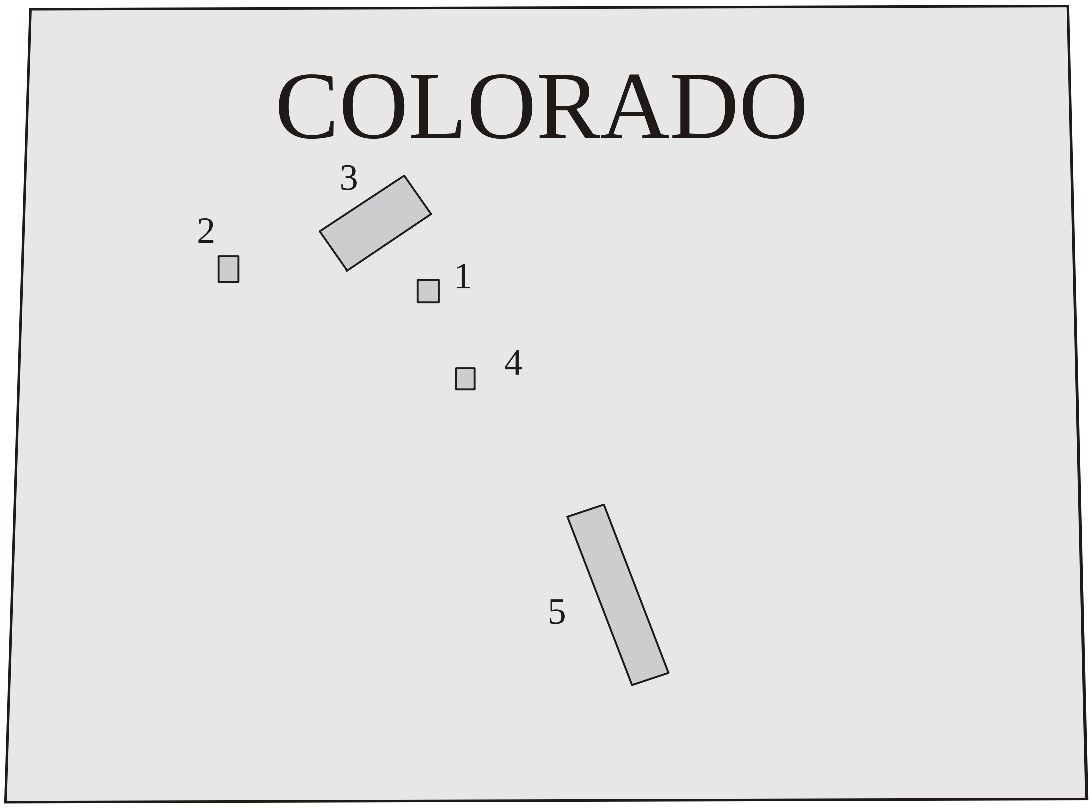


Figure 1. Location of study areas: 1) Redcliff area; 2) Flat Tops Area 3) Eagle Valley area; 4) South Park area; 5) Sangre de Cristo area.

shallow seas invaded the basins and deposited marine sediments from the adjoining mountain uplifts. One of the large basins, the central Colorado trough, extended from northwest Colorado to south-central Colorado and contains between 10,000 to 20,000 feet of Permian and Pennsylvanian rocks of both marine and nonmarine origin (DeVoto, 1972). The earliest basin-deposited sediments of Pennsylvanian age in the central Colorado trough are marine-transitional black shales and sandstone of the Belden Formation. The Minturn Formation and the younger Maroon Formation overlies the Belden Formation and consist of marine and nonmarine sediments accumulated adjacent to the basin margins but pass into evaporite and clastic deposits of the Eagle Valley Evaporite in the center of the basin (Mallory,1971). The Eagle Valley Evaporite between the towns of Avon and Gypsum, consists of a thick sequence of interbedded gypsum, anhydrite, halite, black shale and siltstone formed by evaporation of a narrow seaway.

Along the flanks of the Ancestral Rockies, sediments derived from the eroding mountain uplifts accumulated as valley fill and alluvial fans consisting of arkosic gravels and sands and conglomerates, predominately red in color (redbeds). In south-central Colorado, the Sangre de Cristo Formation of sandstones, conglomerates, and shales was deposited on mudflats with stream channels. The erosion of the Ancestral Rockies and the deposition of sediments in the basins continued into Permian time. By middle Permian time, terrestrial sedimentation had decreased and shallow seas invaded the region.

Evaporite minerals, particularly gypsum, are known to occur in the Pennsylvanian and Permian rocks throughout central Colorado. Gypsum is mined from the central Colorado trough near the town of Gypsum and along the Arkansas River below Salida, Colorado.

Methods

Generally small streams were sampled, usually with a watershed area of around several square miles, although some watersheds are larger. Springs within the watershed were also sampled. Waters were collected from five rock groups of Permian and Pennsylvanian age in western Colorado. The five rock groups are: 1) Pennsylvanian Minturn and Belden Formations in the Redcliff area, 2) Pennsylvanian Minturn and Belden Formations in the Flat Tops area; 3)

Pennsylvanian Minturn and Belden Formations in the Sangre de Cristo Range; 4) Permian and Pennsylvanian Sangre de Cristo Formation in the Sangre de Cristo Range; and 5) Pennsylvanian Eagle Valley Formation, Evaporitic Facies in Eagle Valley and Evaporitic Facies of Minturn and Belden Formations in South Park (Tweto, 1979). The last group is from two areas but because all contain evaporite facies minerals, the two areas are combined and will be referred to as Evaporite Facies of Eagle Valley and South Park. Samples of water were collected from 36 streams and 9 spring sites from July 18 to August 24, 2000. The waters were collected after peak runoff had occurred but prior to the streams reaching base flow or in some cases, drying up completely. Generally, during the time of sampling, the weather was stable and no precipitation occurred. Waters from each of the study areas were usually collected within one or two days. Waters from areas of lower elevations were collected earlier in the season than the higher areas. During the time of sampling, the weather was stable and no precipitation occurred. Samples were collected by width and depth integration (Edwards and Glysson, 1988) or from a point source for springs. Temperature, pH, and conductivity were measured at the site. pH was measured using an Orion model 250 pH meter with an Orion Ross Sure-Flow electrode. Temperature was measured using temperature probe. The conductivity was measured using an Orion model 120 conductivity meter. Samples were collected into high-density polyethylene bottles. For the dissolved cation analyses, a sample was filtered at the site through a 0.45 μm-membrane filter and acidified with ultrapure reagent-grade Ultrex nitric acid to pH < 2. Another sample was filtered but not acidified for anion analyses and an unfiltered, unacidified sample was collected for alkalinity measurement. The samples were stored in an ice chest and later in a refrigerator and kept cool until analyzed.

Upon return to the laboratory, alkalinity as HCO_3^-, was determined by titration with H_2SO_4 using Gran's plot technique (Orion Research, Inc.,1978). Sulfate, chloride, nitrate, and fluoride concentrations were determined by ion chromatography (IC) (Fishman and Pyen, 1979). Cations were analyzed by inductively coupled plasma - mass spectromentry (ICP-MS) or inductively coupled plasma - atomic emission spectrometry (ICP-AES). IC, ICP-AES, and alkalinity analyses were performed by Murdock Environmental Laboratory, University of Montana, Missoula, The ICP-MS analyses were determined by U.S.G.S. laboratories in Denver under the direction of Allen Meier. Duplicate water samples, blank samples, and USGS Water Resource Division standard reference waters were analyzed with each data set. The chemical analyses with date of collection, location, rock type of basin, water type, flow data, and comments are shown for all sites in appendix 1.

Results

Water samples were collected from small streams or springs of watersheds that were mainly within National Forests or Bureau of Land Management lands. The watersheds are generally mountainous headwaters and are not impacted by historic mining. The ranges and means of species and other parameters were determined for each of the five rock groups. A summary of the mean geochemical data of waters collected within each of the groups is shown in Table 1. In addition, total dissolved solids (TDS) values were calculated for each site. The TDS value represents the total amount of solids (mg/L) remaining when a water sample is evaporated to dryness. In calculation from the chemical data, TDS value is the sum of all dissolved constituents with bicarbonate converted to equivalent carbonate in the solid phase, which assumes that half the bicarbonate is volatilized (Hem, 1992). The TDS value is calculated for the waters from each site and is shown in appendix 1.

Minturn and Belden Formations in the Redcliff Area

Water samples were collected from seven tributary streams of Turkey Creek and Eagle River in the Redcliff area in the White River National Forest (fig. 2). The watersheds are underlain by Pennsylvanian Minturn and Belden Formations of sandstone, grit, conglomerate, shale, and carbonate rocks (Tweto, 1979). The relief in the area is high and the dominant vegetation is subalpine forest (Kuchler, 1965). Annual precipitation ranges from 25 to 40 inches (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 2. The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values. Mean pH is 8.33 and mean conductivity is 295 μS/cm. Mean total dissolved solids (TDS) is higher than

Table 1. Means of selected chemistry of waters from areas underlain by Permian and Pennsylvanian sedimentary rocks. Conductivity in µS/cm, alkalinity in mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO4, Cl, F, and N in mg/L, remaining elements in µg/L.

Variable	Minturn and Belden Fms in the Redcliff Area	Minturn and Belden Fms in the Flat Tops Area
n	7	8
pH	8.33	7.82
Conductivity	295	392
TDS	240	312
Ca	41	74
Mg	11	3.1
Na	1.6	1.3
K	0.5	<0.5
Alkalinity	325	402
SO_4	13	5.4
Cl	<1	<1
F	<0.05	<0.05
N	<0.05	0.22
Li	2.5	0.6
Ba	82	45
Sr	102	127
Al	3.6	1.6
Fe	1.3	2.1
Mn	0.36	1
Cu	<0.5	<0.5
Zn	<0.5	<0.5
Mo	0.5	0
Cr	<1	3
Ni	1.2	1.9
U	1.4	0.8

Table 1 cont. Means of selected chemistry of waters from areas underlain by Permian and Pennsylvanian sedimentary rocks. Conductivity in µS/cm, alkalinity in mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO4, Cl, F, and N in mg/L, remaining elements in µg/L.

Variable	Minturn and Belden Fms in the Sangre de Cristo Area	Evaporite Facies of Eagle Valley and South Park	Sangre De Cristo Formation
n	6	11	11
pH	8.15	8.09	7.86
Conductivity	429	685	172
TDS	334	528	137
Ca	57	103	24
Mg	19	21	4
Na	3.2	7.8	1.9
K	1.3	1.2	<0.5
Alkalinity	322	369	179
SO_4	64	155	6.6
Cl	<1	3.6	<1
F	0.09	0.08	<0.05
N	<0.05	<0.05	<0.05
Li	1.9	4.0	1.1
Ba	42	56	66
Sr	472	1071	121
Al	2.3	2.7	1.6
Fe	2.4	10	1.8
Mn	0.58	4.1	0.23
Cu	0.5	1	<0.5
Zn	1.1	1.7	<0.5
Mo	1.8	1.8	0.3
Cr	1	1	1.1
Ni	1.7	3.2	0.7
U	1.3	1.5	0.35

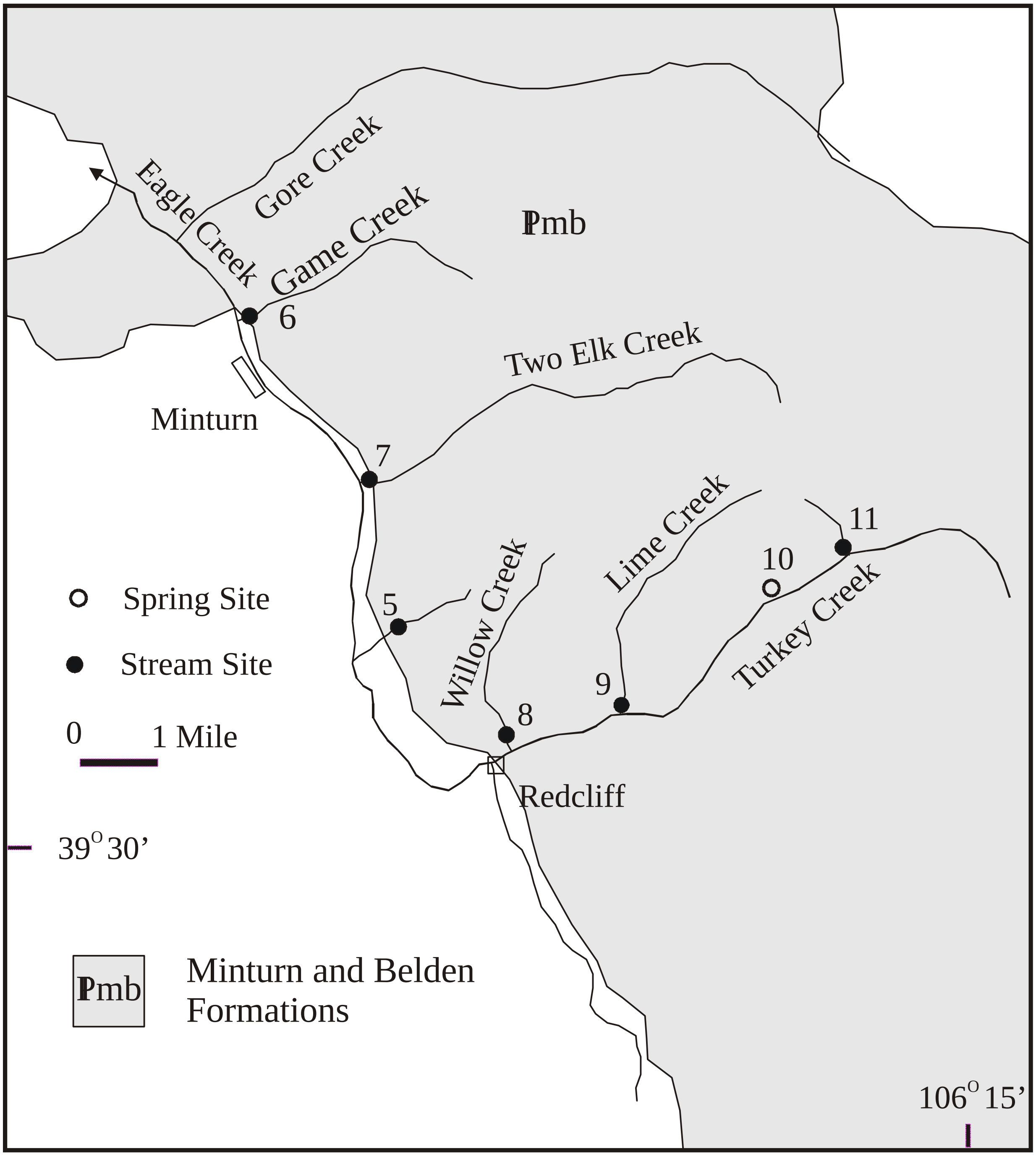


Figure 2. Locations of water samples from stream and spring sites in the Redcliff area. Geology generalized from Tweto (1979).

Table 2. Summary of selected water chemistry of six streams and one spring in watersheds underlain by Pennsylvanian Minturn and Belden Formations in the Redcliff area (n=7). Conductivity in µS/cm, alkalinity as mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO_4, Cl, F, and N in mg/L, remaining elements in µg/L. Values below level of detection were replaced with values of 0.7 the level of detection.

Measurement	Range		Mean
	Minimum	Maximum	
Conductivity	187	564	295
TDS	159	426	240
pH	7.47	8.57	8.33
Ca	29	86	41
Mg	2.5	19	11
Na	1.3	2.3	1.6
K	0.3	1.1	0.5
Si	2.9	4.7	3.3
Alkalinity	239	393	325
SO_4	2.5	119	13
Cl	<1	<1	<1
F	<0.05	0.05	<0.05
N	<0.05	0.08	<0.05
Al	2.1	7.4	3.6
Fe	1	2	1
Mn	0.1	4.2	0.4
Cu	<0.5	0.6	<0.5
Zn	<0.5	0.7	<0.5
Mo	0.3	1.3	0.5
Cr	<1	1	<1
Ni	0.8	2.1	1.2
U	1	2.1	1.4
Li	1.3	4.1	2.5
Ba	62	167	82
Sr	53	597	102

average river water (Table 3) with a mean of 240 mg/L. The mean concentrations of Fe, Al, and Mn are low compared to average river water with values of 1, 0.4, and 3.6 mg/L, respectively. Other trace metals are also low. Mean concentrations of Zn, Cu, Mo, and U are <0.5, <0.5, 0.5, and 1.4. Si concentrations are low with a mean of 3.3 mg/L probably because of the rock type which contains abundant carbonate minerals as well a gypsum. Alkalinity values are high with a mean of 325 mg/L, probably because of the carbonate rocks within the formations. Mean Cl content is < 1 mg/L, which is low and reflects the short residence time of the melting snow and storm runoff in contact with the rocks and lack of significant evaporation. Because of the high alkalinity values, the areas underlain by rocks of the Minturn and Belden Formations in the Redcliff area are moderately resistant to introduced acidification, such as a coal-burning power plant or acidity from mining wastes. The chemical quality of the waters from watersheds underlain by Pennsylvanian Minturn and Belden Formations in this area is good.

Minturn and Belden Formations in the Flat Tops Area

Samples of water were collected from three streams and five springs in the Flat Tops area in the White River National Forest (fig. 3). The watersheds are underlain by Pennsylvanian Belden and Minturn Formations of sandstone, grit, conglomerate, shale, and carbonate rocks (Tweto, 1979). Relief is high along the flanks but the upland area containing the springs is generally flat lying. The dominant vegetation is subalpine forests with alpine meadows in the upland area (Kuchler, 1965). Annual precipitation ranges from 20 to 40 inches (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 4. The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values. Mean pH is 7.82 and mean conductivity is 392 µS/cm. Mean TDS value is higher than average river water (Table 3) with a mean of 312 mg/L. Mean concentrations of Al, Fe, and Mn are low with means of 1.6, 2, and 1 µg/l, respectively. Other trace metals are also low. Mean Zn, Cu, Mo, and U are <0.5, <0.5 , 0.4, and 0.8 µg/l, respectively. Mean Si concentration is low with a mean of 4.3 mg/L probably because of the rock type which contains abundant carbonate minerals as well a gypsum. The mean Cl concentration is < 1 mg/L, which is low and reflects the short residence time of the

Table 3. Background of trace metals in freshwater and chemical analyses of mean river water

Background of trace metals (μg/L) in freshwater	
Element	Data after Forstner and Wittmann (1979)
Al	<30
Fe	<30
Mn	<5
Cu	1.8
Zn	10
As	2
Mo	1
Pb	0.2
Sb	0.1
Cr	0.5
Ni	0.3
Li	1
Se	0.1
U	0.5

Chemical analyses (in mg/L) of mean river water	
Element in mg/L	Data from Livingstone (1963)
Ca	15
Mg	4.1
Na	6.3
K	2.3
Si	6.1
SO_4	11.2
HCO_3	58.4
Cl	7.8

Calculated TDS in mg/L	81.5

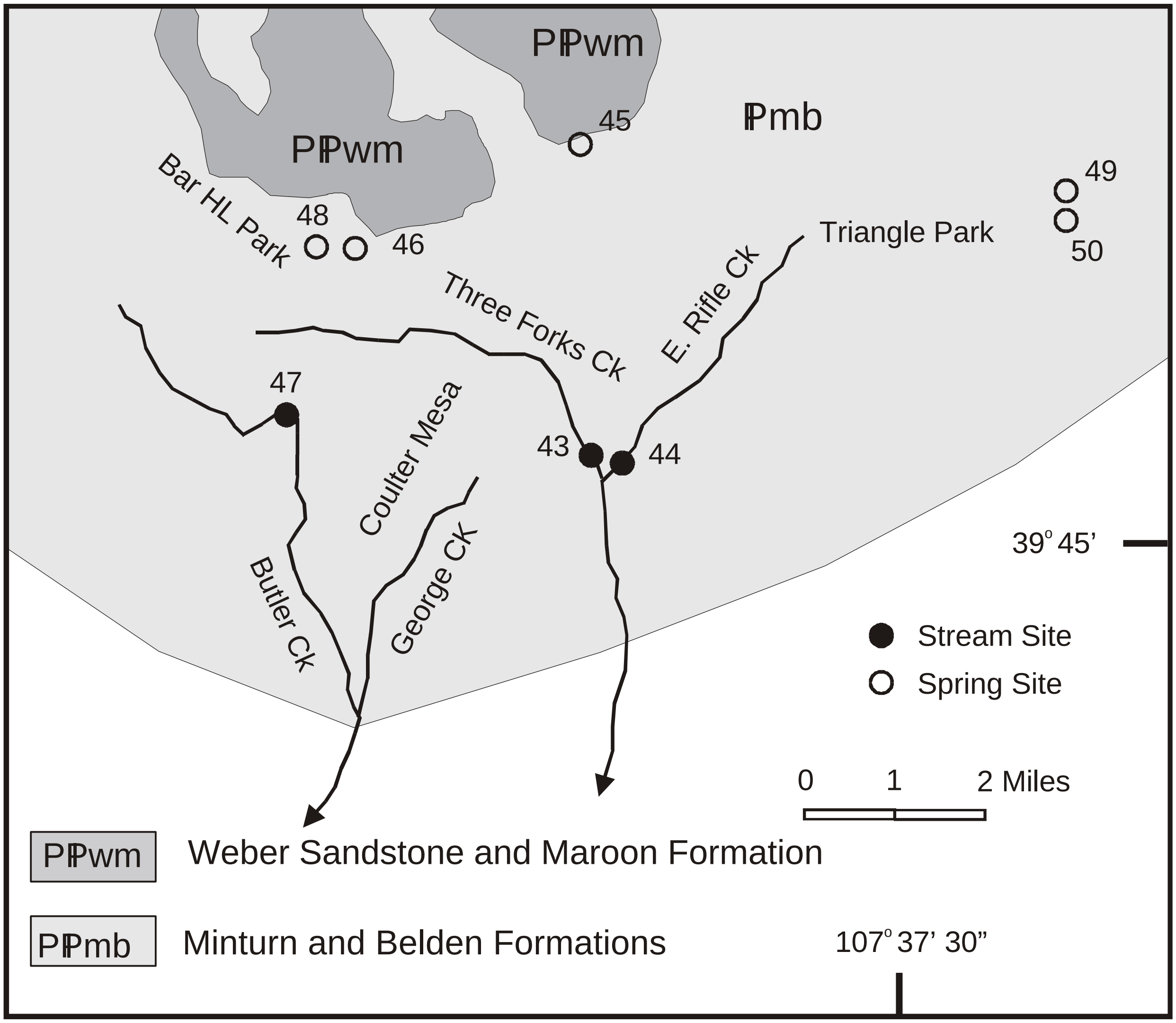


Figure 3. Locations of water samples from streams and springs in the Flat Tops area. Geology generalized from Tweto (1979).

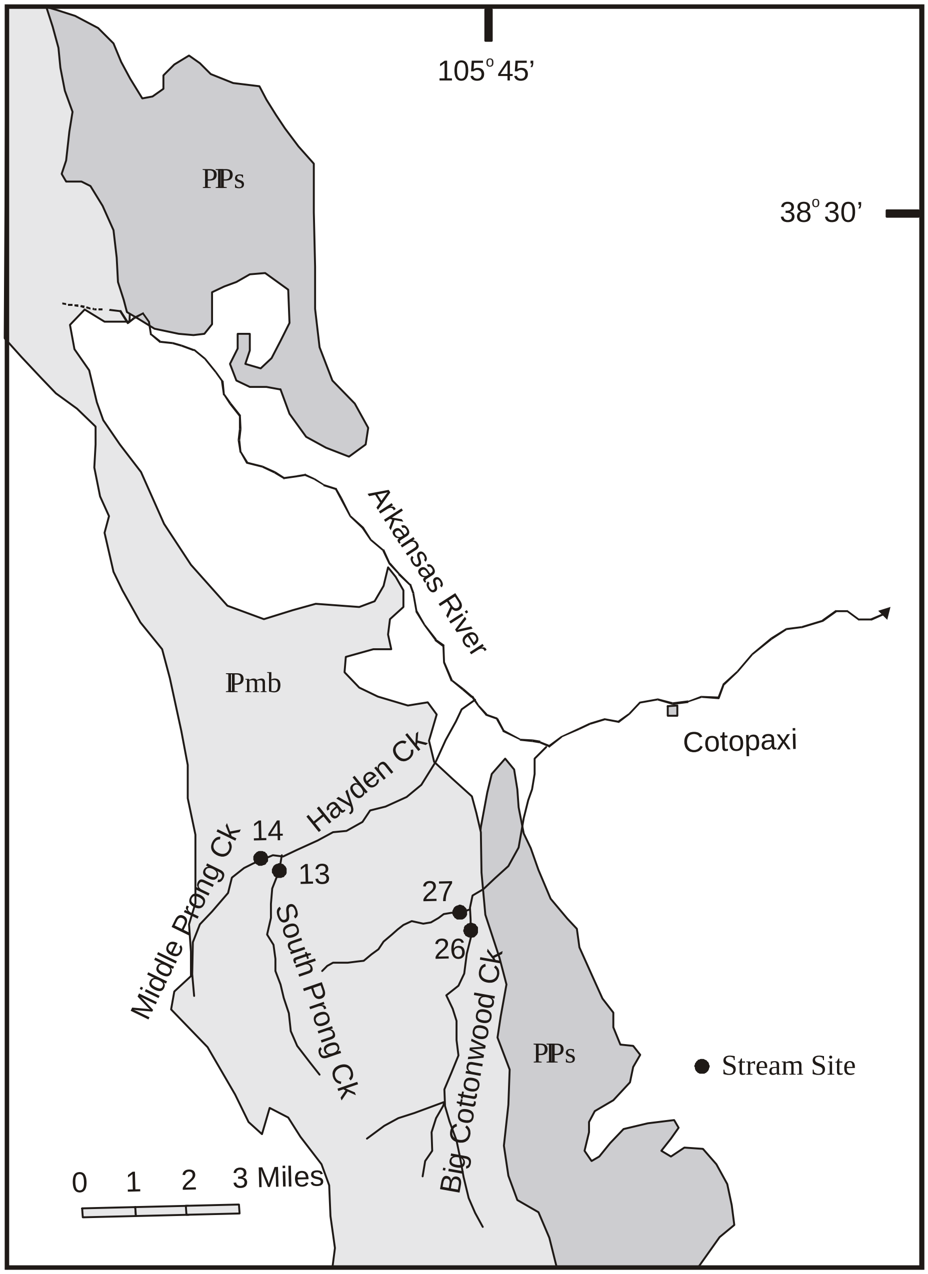
Table 4. Summary of selected water chemistry of three streams and five springs in watersheds underlain by Pennsylvanian Minturn and Belden Formations in the Flat Tops Area. (n=8). Conductivity in µS/cm, alkalinity as mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO_4, Cl, F, and N in mg/L, remaining elements in µg/L Values below level of detection were replaced with values of 0.7 the level of detection.

Measurement	Range		Mean
	Minimum	Maximum	
Conductivity	296	633	392
TDS	228	479	312
pH	7.46	8.31	7.82
Ca	58	108	74
Mg	1.1	18	3.1
Na	1	2.3	1.3
K	<0.5	0.55	<0.5
Si	3.7	5	4.3
Alkalinity	326	465	402
SO_4	1.4	143	5.4
Cl	<1	1.1	<1
F	<0.05	0.1	<0.05
N	<0.05	0.87	0.22
Al	0.9	2.2	1.6
Fe	1	14	2
Mn	0.02	13	1
Cu	<0.5	0.6	<0.5
Zn	<0.5	0.6	<0.5
Mo	<0.2	2.2	0.4
Cr	2.1	2.8	2.5
Ni	1.4	2.9	1.9
U	0.4	2.4	0.8
Li	0.3	2.9	0.6
Ba	34	60	45
Sr	53	1040	127

water from melting snow and rain in contact with the rocks and the lack of significant evaporation. Alkalinity values are high with a mean 402 mg/L, which indicates good acid-neutralizing capacity probably because of abundant carbonate minerals in the rocks. Because of the high alkalinity values, the areas underlain by rocks of the Minturn and Belden Formations are moderately resistant to introduced acidification. The chemical quality of the waters from watersheds underlain by Pennsylvanian Minturn and Belden Formations in this area is good.

Minturn and Belden Formations in the Sangre de Cristo Range

Samples of water were collected form six streams in the northern Sangre de Cristo Range within the San Isabel and Rio Grande National Forest (figs. 4 and 5). The watersheds are underlain by Pennsylvanian Minturn and Belden Formations of shale, siltstone, and sandstone with beds of gypsum and marine limestone (Tweto, 1979). Relief is high and the dominant vegetation is pine-Douglas fir and spruce-fir forest in the higher areas and juniper-pinyon woodland along the lower flanks (Kuchler, 1965). Annual precipitation ranges from 16 to 40 inches (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 5. The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values. Mean pH is 8.15 and mean conductivity is 429 µS/cm. Mean TDS value is higher than average river water (Table 3) with a mean of 334 mg/L. The mean concentrations of Al, Fe, and Mn are low with means of 2.3, 2, and 0.6 µg/l, respectively. Other trace metal concentrations are low. Mean concentrations of Zn, Cu, Mo, and U are 1.1, 0.5 , 1.8, and 1.3 µg/l, respectively. Mean Si concentration is 5.2 mg/L probably because of the rock type which contains abundant carbonate minerals as well a gypsum. Mean Cl concentration is < 1 mg/L, which is low and reflects the short residence time of the water from melting snow and rain in contact with the rocks and the lack of significant evaporation. Mean alkalinity as HCO_3^- is 322 mg/L, which indicates good acid-neutralizing capacity probably because of abundant carbonate minerals in the rocks. Because of the high alkalinity values, the areas underlain by rocks of the Minturn and Belden Formations are moderately resistant to introduced acidification. The chemical quality of the waters from watersheds underlain by Pennsylvanian Minturn and Belden Formations is good.



PIPs Sangre de Cristo Formation

IPmb Minturn and Belden Formation

Figure 4. Locatins of waters from stream sites in the northern Sangre de Cristo Range. Geology generalized from Tweto (1979).

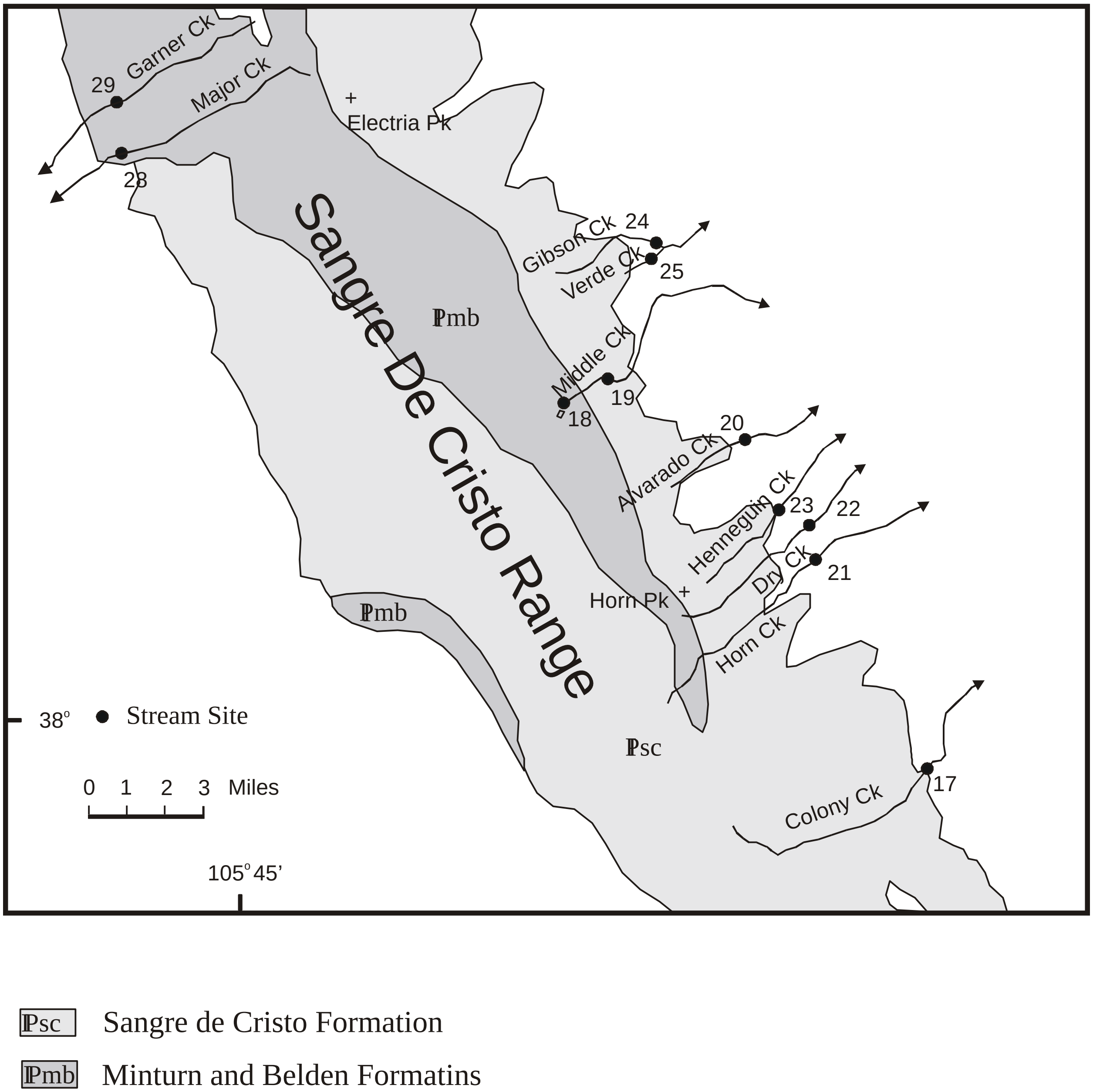


Figure 5. Locations of water samples from streams from the Sangre de Cristo Range. Geology generalized from Tweto (1979).

Table 5. Summary of selected water chemistry of six streams in watersheds underlain by Pennsylvanian Minturn and Belden Formations in the Sangre de Cristo Range (n=6). Conductivity in µS/cm, alkalinity mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO_4, Cl, F, and N in mg/L, remaining elements in µg/L. Values below level of detection were replaced with values of 0.7 the level of detection

Measurement	Range		Mean
	Minimum	Maximum	
Conductivity	235	632	429
TDS	197	469	334
pH	7.11	8.56	8.15
Ca	31	91	57
Mg	11	30	19
Na	1.3	4.7	3.2
K	0.64	3.2	1.3
Si	3.1	7	5.2
Alkalinity	285	444	322
SO_4	6.2	169	64
Cl	<1	1.3	<1
F	<0.05	0.15	0.09
N	<0.05	0.07	<0.05
Al	0.88	6.3	2.3
Fe	1	5	2
Mn	0.3	7.6	0.6
Cu	<0.5	0.9	0.5
Zn	0.5	19	1.1
Mo	0.53	8.1	1.8
Cr	<1	3.2	1
Ni	0.9	2.6	1.7
U	1	1.8	1.3
Li	0.5	4.5	1.9
Ba	38	47	42
Sr	120	1310	472

Evaporitic Facies in the Eagle Valley and South Park Areas

Samples of water draining Evaporite Facies rocks were collected form five streams and three springs in the Eagle Valley and two streams and one well in the South Park area (figs. 6, 7 and 8). Because the water samples were from areas underlain with rocks containing evaporite minerals, particularly gypsum, the samples from the two areas were lumped together. The watersheds in the Eagle Valley are underlain by Pennsylvanian Eagle Valley Evaporite of gypsum, anhydrite and interbedded siltstone and minor dolomite and Pennsylvanian Eagle Valley Formation of siltstone, shale, sandstone, carbonate, and lenses of gypsum (Tweto, 1979). The watersheds of the South Park area are underlain by the evaporite facies member of the Pennsylvanian Minturn and Belden Formations (Tweto, 1979). Relief varies from high in the Eagle Valley and moderate to low in the South Park area. The dominant vegetation is western spruce-fir forest in the higher areas and juniper-pinyon scrub and sagebrush along the flanks and Eagle Valley and alpine meadow and grasslands in South Park (Kuchler, 1965). Annual precipitation ranges from 12 to 30 inches in the Eagle Valley and 12 to 25 inches in South Park (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 6. The sites contain nine Ca^{2+}- HCO_3^- and two Ca^{2+}-SO_4^{2-} type waters with alkaline pH values. Mean pH is 8.09 and mean conductivity is 685 µS/cm. Mean TDS value is higher than average river water (Table 3) with a mean of 334 mg/L. Trace metal concentrations are low. Mean concentrations of Al, Fe, and Mn are moderately low with means of 2.7, 10, and 4.1 µg/l, respectively. Other trace metal concentrations are low. Mean Zn, Cu, Mo, and U are 1.7, 1, 1.8, and 1.5 µg/l, respectively. Mean Si concentration 7.5 mg/L. Mean Cl concentration is 3.6 mg/L, which is slightly higher than the waters from the other rock composition types probably because of the presence of minor halite in the Evaporite Facies rocks. Mean alkalinity is 369 mg/L, which indicates good acid-neutralizing capacity probably because of abundant carbonate minerals in the rocks. Because of the high alkalinity values, the areas underlain by rocks containing evaporite minerals are moderately resistant to introduced acidification. The

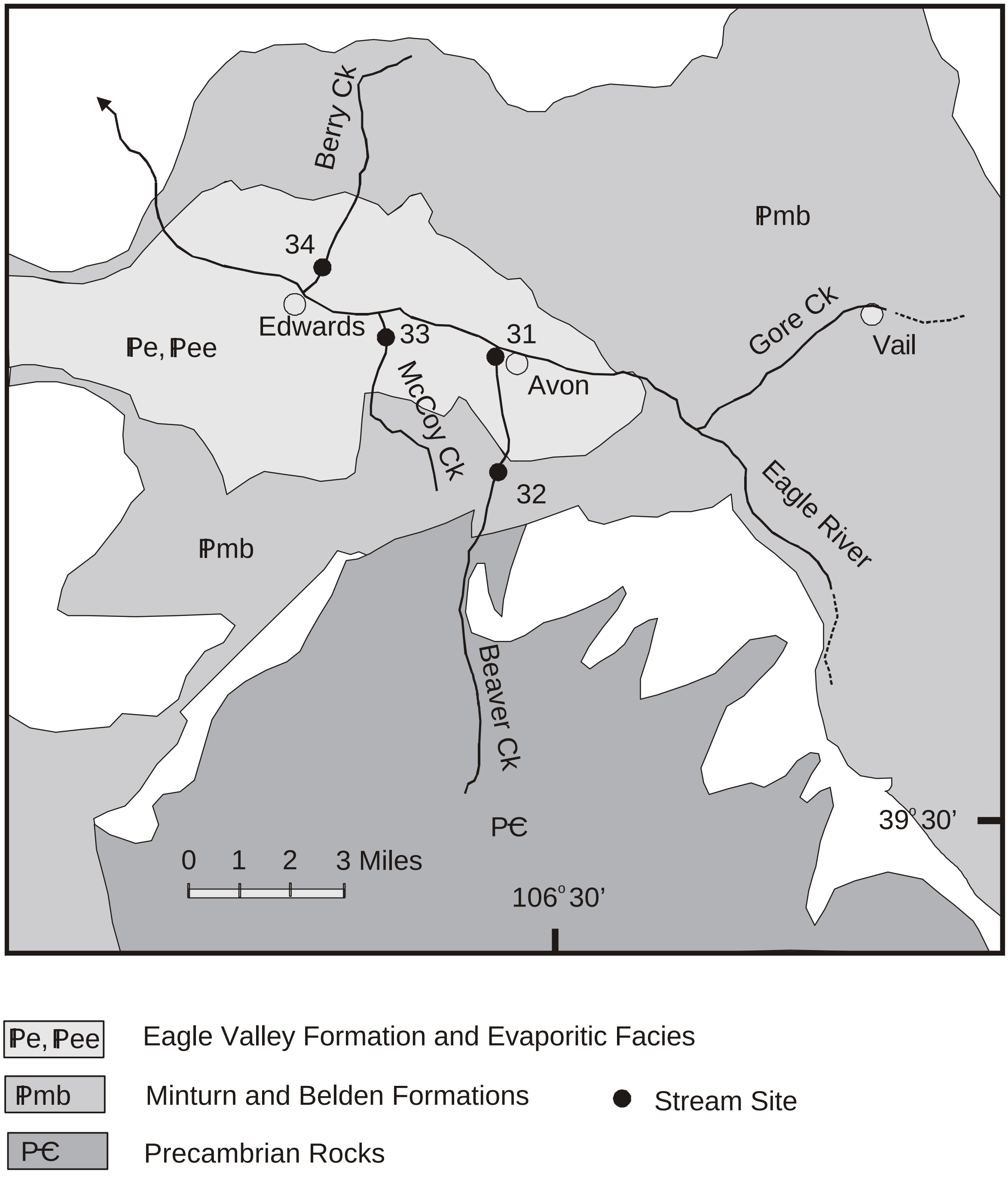
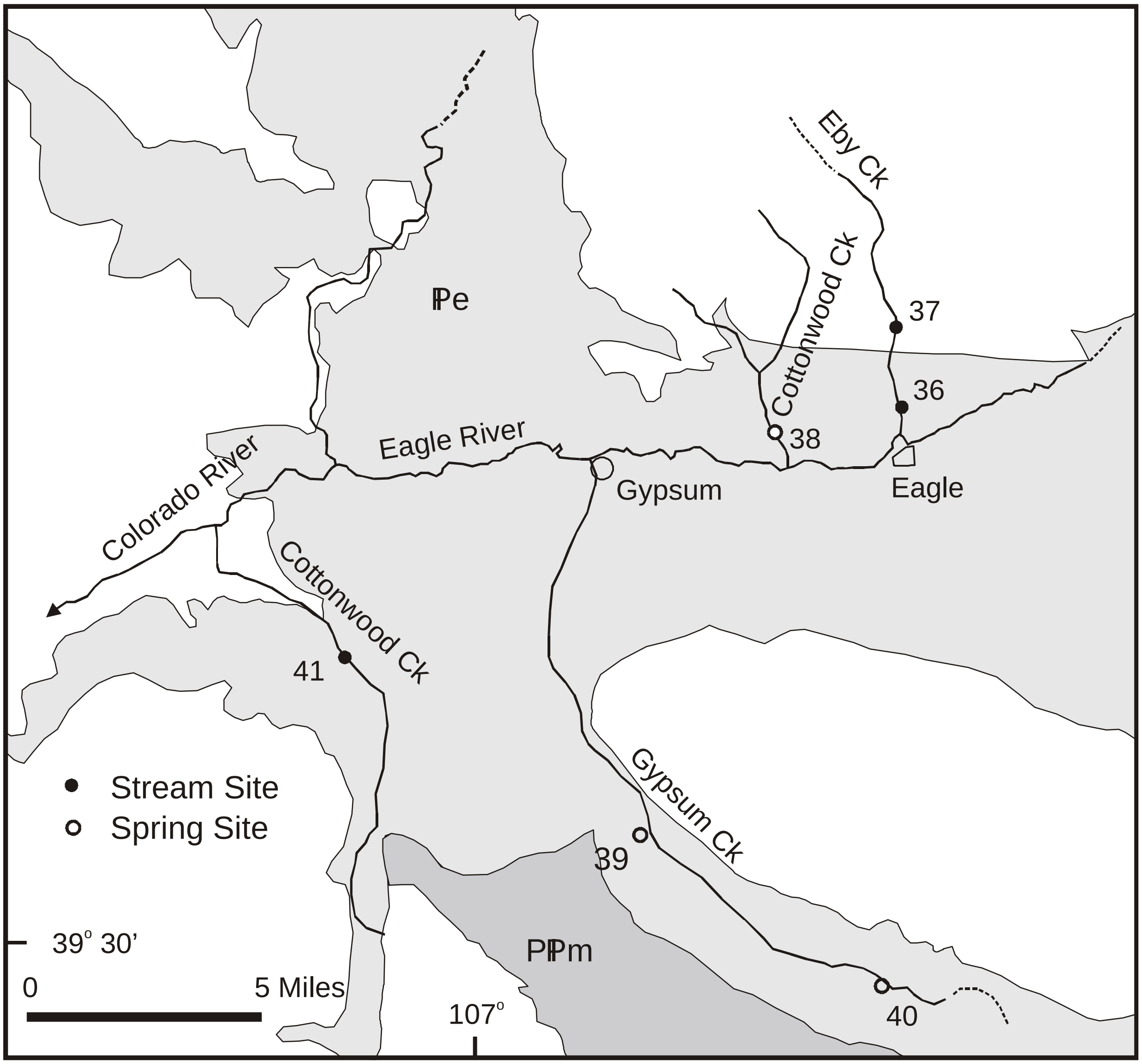


Figure 6. Locations of water samples from steams in the Upper Eagle River Valley. Geology is generalized from Tweto (1979).



PPm Maroon Formation

Pe Evaporitic Facies

Figure 7. Locations of water samples from stream and spring sites in the lower Eagle River Valley. Geology generalized from Tweto (1979).

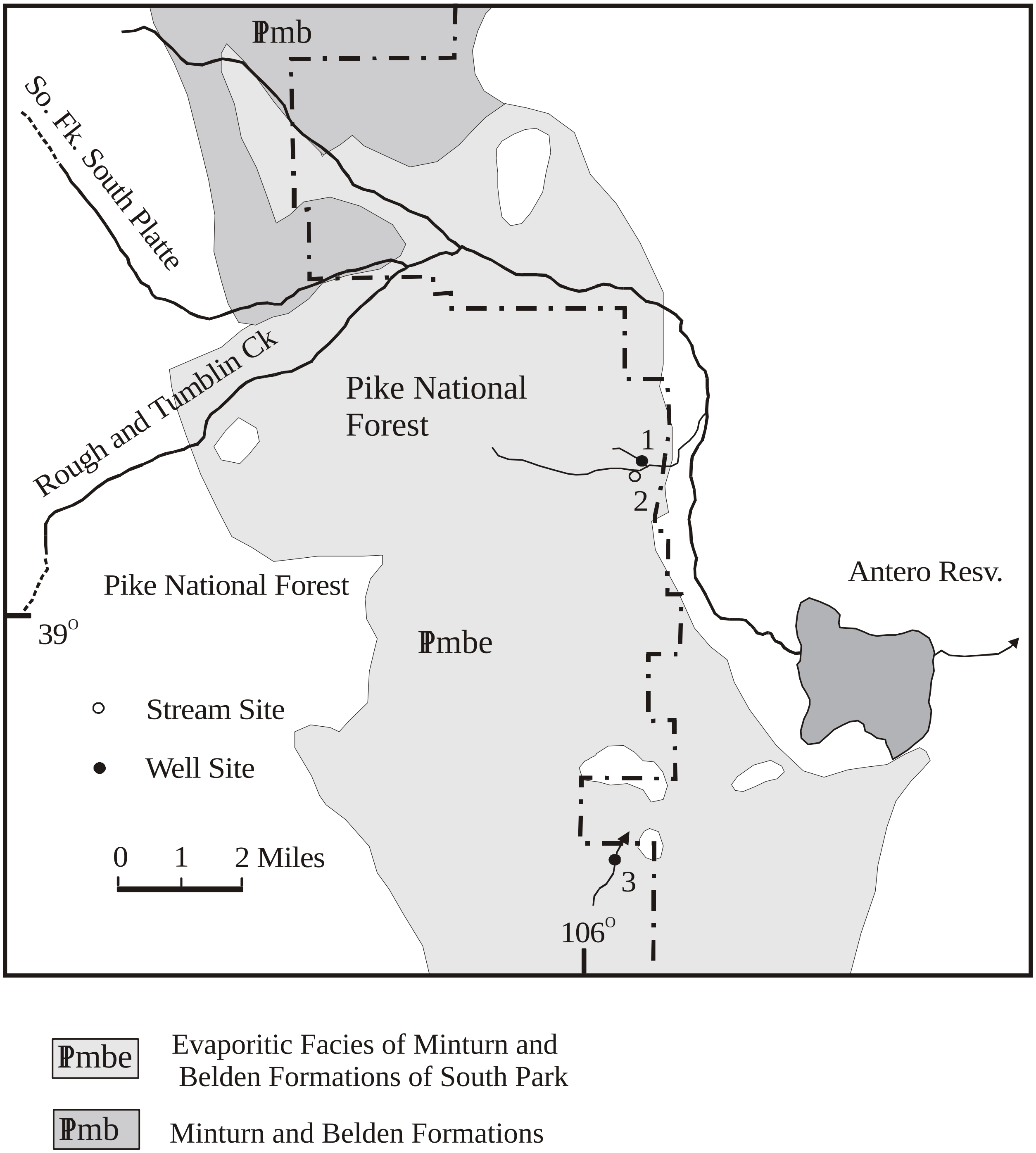


Figure 8. Locations of water samples from stream and well sites in South South Park. Geology generalized from Tweto (1979).

Table 6. Summary of selected water chemistry of eight streams, two springs and one well in watersheds underlain by Pennsylvanian Evaporite Facies rocks in Eagle Valley and South Park (n=11). Conductivity in µS/cm, alkalinity as mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO_4, Cl, F, and N in mg/L, remaining elements in µg/L. Values below level of detection were replaced with values of 0.7 the level of detection

Measurement	Range		Mean
	Minimum	Maximum	
Conductivity	232	2020	685
TDS	169	1757	528
pH	7.49	8.65	8.09
Ca	30	387	103
Mg	7	74	21
Na	2.7	60	7.8
K	<0.5	5.6	1.2
Si	3.8	14	7.5
Alkalinity	177	575	369
SO_4	19	972	155
Cl	<1	24	3.6
F	<0.05	0.89	0.08
N	<0.05	0.07	<0.05
Al	0.88	8.2	2.7
Fe	1	20	10
Mn	0.06	441	4.1
Cu	<0.5	2.3	1
Zn	<0.5	123	1.7
Mo	0.5	8.6	1.8
Cr	<1	3.8	1
Ni	1.1	14.4	3.2
U	0.37	6.1	1.5
Li	<0.1	110	4
Ba	20	116	56
Sr	215	4720	1071

chemical quality of the waters from watersheds underlain by Evaporite Facies rocks is good except for moderately high total dissolved solids.

Sangre de Cristo Formation in the Sangre de Cristo Range

Water samples were collected from 11 streams in the Sangre de Cristo Range within the San Isabel and Rio Grande National Forest (figs. 5 and 9). The watersheds are underlain by Permian and Pennsylvanian Sangre de Cristo Formation of conglomerate, arkose, sandstone, siltstone, and minor shale and limestone (Johnson, 1969). Relief is high and the dominant vegetation is pine-Douglas fir and western spruce-fir forest in the higher areas and juniper-pinyon woodland along the lower flanks (Kuchler, 1965). Annual precipitation ranges from 16 to 40 inches (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 7. The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values. Mean pH is 7.86 and mean conductivity is 172 µS/cm. Mean TDS value is higher than average river water (Table 3) with a mean of 137 mg/L. Mean concentrations of Al, Fe, and Mn are low with means of 1.6, 2, and 0.23 µg/l, respectively. Other trace metal concentrations are low. Mean concentrations of Zn, Cu, Mo, and U are <0.5, <0.5 , 0.26, and 0.35 µg/l, respectively. Mean Si concentration is 3.4 mg/L. The low mean compared to average waters is probably due to the rock type which contains abundant course silicate grains which are less soluble than finer grain silicate minerals. Mean Cl concentration is < 1 mg/L, which is low and reflects the short residence time of the water from melting snow and rain in contact with the rocks and the lack of significant evaporation. Mean alkalinity is 172 mg/L, probably because of the presence of minor carbonate minerals in the rocks and indicates acid-neutralizing capacity. The chemical quality of the waters from watersheds underlain by Permian and Pennsylvanian Sangre de Cristo Formation is good.

Comparison of Water Chemistry from each of the Five Rock Groups

The chemistry of water evolving in watersheds depends on the chemical composition of

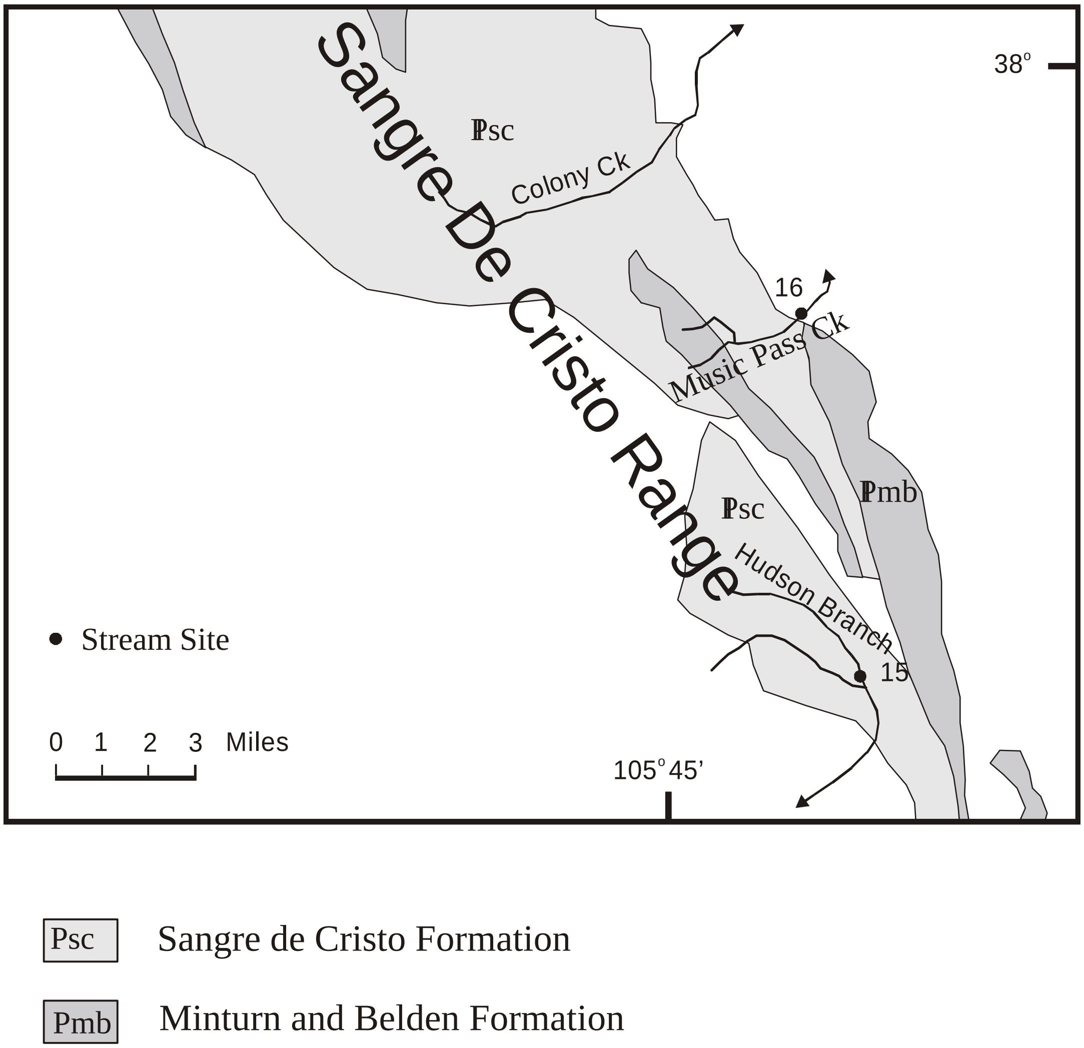


Figure 9. Locations of water samples from streams in the Sangre de Cristo Range. Geology is generalized from Tweto (1979).

Table 7. Summary of selected water chemistry of 11 streams in watersheds underlain by Permian and Pennsylvanian Sangre de Cristo Formation in the Sangre de Cristo Range (n=11). Conductivity in µS/cm, alkalinity as mg/L HCO_3, TDS, Ca, Mg, Na, K, Si, SO_4, Cl, F, and N in mg/L, remaining elements in µg/L. Values below level of detection were replaced with values of 0.7 the level of detection.

Measurement	Range		Mean
	Minimum	Maximum	
Conductivity	63	294	172
TDS	58	246	137
pH	7.13	8.99	7.86
Ca	6.9	39	24
Mg	1.9	11	4.1
Na	1	5.7	1.9
K	<0.5	0.57	<0.5
Si	1.5	6.6	3.4
Alkalinity	81	359	179
SO_4	1.8	55	6.6
Cl	<1	<1	<1
F	<0.05	0.14	<0.05
N	<0.05	<0.05	<0.05
Al	0.22	11	1.6
Fe	<1	16	2
Mn	<0.01	4.4	0.23
Cu	<0.5	0.6	<0.5
Zn	<0.5	1	<0.5
Mo	<0.2	1.4	0.26
Cr	<1	14	1.1
Ni	0.3	1.2	0.7
U	0.03	1.9	0.35
Li	0.6	304	1.1
Ba	15	186	66
Sr	36	364	121

the underlying rock type. A unique range of water chemistry evolves within each of the five rock groups (Table 1). Values of TDS can be used to compute the rate at which rivers transport chemical weathering products to the ocean and therefore chemical weathering rates at a point in time but not an annual rate. Even so, TDS values can be used to compare waters from different geologic terrains as a means of comparing chemical weathering rates. Mean TDS values for waters from the five areas are shown in Table 1. Waters with the highest mean TDS values evolve from areas underlain by Evaporite Facies rocks in the Eagle Valley and South Park followed by Minturn and Belden Formations in the Sangre de Cristo Range, Minturn and Belden Formations in the Flat Tops area, Minturn and Belden Formations in the Redcliff area, and Sangre de CristoFormation in the Sangre de Cristo Range.   The areas underlain by Evaporite Facies rocks in the Eagle Valley and South Park are undergoing by far the most rapid rate of chemical weathering, supplying the most dissolved solids to the waters of the area. This is not surprising because these rocks contain evaporite minerals, particularly gypsum, which are readily soluble. Watersheds underlain by Pennsylvanian Sangre de CristoFormation in the Sangre de Cristo Range are undergoing the lowest rate of chemical weathering and supplying the lowest amounts of dissolved solids to the waters of the area. These rocks contain sandstones and conglomerates more resistance to weathering and lack the more soluble carbonate and evaporite minerals such as gypsum of the other rock groups.

Alkalinity of a solution is the capacity for solutes it contains to react with and neutralize acid (Hem, 1992). The property of alkalinity is determined by titration with a strong acid. Several different solute species may contribute to alkalinity, but for almost all natural fresh waters, the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate (Hem, 1992). Alkalinity in this study is reported as equivalent amounts of bicarbonate and is a measure of the capacity of the water to react with and consume acid. If an area is affected by introduced acidity from sources such as acid mine drainage or acid rain, the alkalinity will consume the introduced acid. If all the alkalinity is consumed and acidity is still being introduced, the acidity of the water will increase. The higher the alkalinity value, the greater the capacity of the water to consume acid. The mean alkalinity values of waters from areas underlain by the five rock groups range from 179 to 402 mg/L as HCO_3^- (Table 1). The waters with the highest alkalinity values are from areas underlain by Minturn and Belden Formations in the Flat Tops area, followed by Evaporite Facies in the Eagle Valley and South Park, Minturn and Belden Formations in the Redcliff area, and Minturn and Belden Formations in the Sangre de Cristo Range. The lowest alkalinity values are from areas underlain by Sangre de Cristo Formation in the Sangre de Cristo Range. The waters from areas underlain by Minturn and Belden Formations and the Evaporite Facies are very well buffered and have large capacity to neutralize acidity.

Mean pH values of waters from areas underlain by the five rock groups are all alkaline and range from 7.82 to 8.33 (Table 1). In addition to rock type, pH values in these headwater streams are affected by the amount of melting snow runoff as a component of the total flow and the time of contact of water and rock. The snow runoff will generally lower the pH, and the time of contact of water and rock will generally increase the pH value. In addition, high biotic activity in the soil zone may release organic acids and may lower pH. The lowest mean pH values are from Belden and Minturn Formations in the Flat Tops area and the Sangre de Cristo Formation in the Sangre de Cristo Range. Both areas have the large components of snow runoff which probably accounts for the lower pH values compared to the remaining rock groups.

Mean concentrations of Si in waters from areas underlain by the five rock groups range from 3.3 to 7.5 mg/L (Table 1). These values are low for four of the rock groups compared to average fresh water of 6.1 mg/L (Table 3). The highest mean value is from areas underlain by evaporites, probably because these rocks contain fine-grained silicate minerals with high surface areas, particularly susceptible to the dissolution of silica. The other four rock types contain coarser grain-size silicate minerals which are more resistant to weathering.

Mean concentrations of Cu, Zn, Fe, Mn, and Mn in waters from the five rock groups are low (Table 1), compared to average fresh water (Table 3). Mean Mo concentrations are low except from areas underlain by Minturn and Belden Formations from the Sangre de Cristo Range and Evaporite Facies from Eagle Valley and South Park. Mean U is high for all rock groups except the Sangre de Cristo Formation and mean Cr and Ni concentrations are high for the five rock groups (Table 1). Mean sulfate concentrations are high for the five rock groups compared to fresh water except for waters from areas underlain by Minturn and Beldon Formations in the

Flat Tops area and the Sangre de Cristo Formation in the Sangre de Cristo Range. Waters from areas underlain by Minturn and Beldon Formations in the Flat Top area is low in sulfate probably because of the large component of snow melt in the waters. The source of sulfate in waters is probably gypsum in all the rock types except for waters from the Sangre de Cristo Formation in the Sangre de Cristo Range.   By far the highest mean sulfate in waters (155 mg/L) is from areas underlain by Evaporite Facies in Eagle Valley and South Park, which contains the highest amounts of gypsum. Mean Li concentrations are high except from areas underlain by Minturn and Belden Formations in the Eagle Valley. Mean nitrate values are low for all waters suggesting little or no anthropogenic contamination.

A comparison of water chemistry from the three areas underlain by Minturn and Belden Formations shows that waters from areas underlain by Minturn and Belden Formations in the Sangre de Cristo Range have the highest TDS values and sulfate concentrations (Table 1). The likely source of the sulfate is gypsum, so these rocks probably contain more evaporite minerals, particularly gypsum, than the other two areas. The waters from the Flat Tops area contained the lowest amount of sulfate, and this area probably contains the least amount of evaporite minerals of the three areas containing Minturn and Belden Formation rocks. But waters from the Flat Top area contain the highest alkalinity (Table 1) indicating that these waters are in contact with more carbonate rocks than the other two areas.

Chemical Modeling of the Waters

To gain understanding of processes such as speciation of elements and identification of minerals that may control the concentration, mobility, and attenuation of elements in the stream waters, chemical modeling of the waters was carried out using PHREEQC (Parkhurst, 1995). The modeling program assumes mineral-solution equilibrium. For some chemical reactions, particularly with slow kinetics, this may not be the case. Except for Al, most of the cations in the stream waters occur mostly as simple cations and the anions as chloride, sulfate, carbonate, and bicarbonate complexes (Table 8). Si occurs as the uncharged specie $H_4SiO_4^0$. In addition, the state of saturation of the waters with mineral phases were calculated. Saturation indices were

Table 8. Dominant species of selected elements in waters

Element	Specie
Ca	Ca^{2+}
Mg	Mg^{2+}
Na	Na^{+}
K	K^{+}
S	SO_4^{2-}
C	HCO_3^{-}
Cl	Cl^{-}
F	F^{-}
Si	$H_4SiO_4^{0}$
Al	$Al(OH)_4^{-}$
Fe	Fe^{2+}, $FeCO_3^{0}$, $Fe(OH)_3^{0}$
Mn	Mn^{3+}, $MnCO_3^{0}$

calculated for a suite of minerals to determine if concentrations of trace metals in water were controlled by mineral phases. The saturation index is a convenient means of expressing saturation states of minerals (Barnes and Clark, 1969) where:

$$SI=\log_{10} IAP/K_T.$$

In the expression, SI is the saturation index, IAP is the ion activity product, and K_T is the equilibrium constant of the dissolution reaction at the temperature of the sample. Mineral phases are supersaturated at SI>0, saturated at SI=0, and undersaturated at SI<0.

Each water sample was modeled and the results for selected minerals are shown in Table 9. Waters from areas underlain by the five rock groups are mostly supersaturated or near saturated with respect to calcite.   Many are supersaturated or near saturation with respect to barite and dolomite. These minerals appear to control the solubility of Ca, Mg, Ba, and alkalinity. Another mineral which has an influence on the control of species in water is chalcedony. The waters from all the rock groups are slightly undersaturated with respect to chalcedony, which appears to control the amount of dissolved silica in the waters. The waters are all undersaturated with respect to other minerals such as siderite, gypsum, fluorite, sepiolite, and rhodochrosite except for one water supersaturated with respect to sepiolite from Evaporite Facies rocks in South Park. Of the five rock groups, waters from Evaporite Facies rocks in the Eagle Valley and South Park come closest to saturation with respect to gypsum, which is not surprising since these rocks contain abundant gypsum.

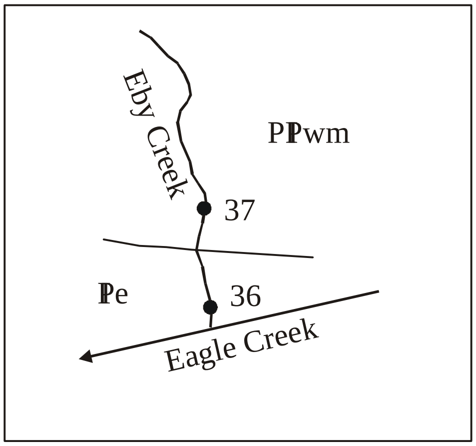
Comparison of Water Chemistry of Two Streams From Above and Below Contact with Evaporite Facies Rocks and Potential Environmental Problems Associated with Construction in the Eagle Valley

The changes of water chemistry of a stream as it crosses the contact and comes into contact with Evaporite Facies rock are shown for Eby and Beaver Creeks (fig.10). Upper Eby

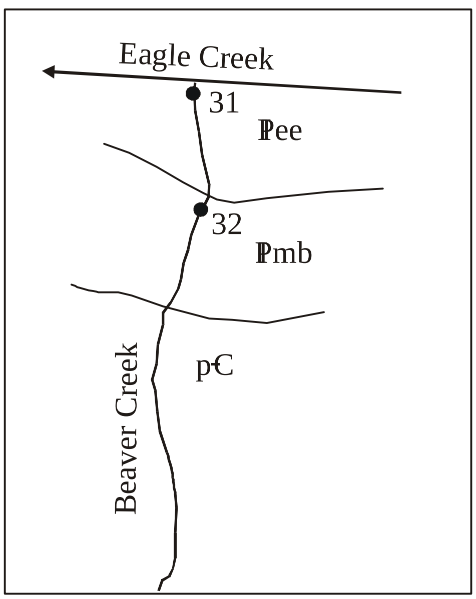
Table 9. Saturation indices for selected minerals for waters from Permian and Pennsylvanian Rocks, Western Colorado

Site	Barite	Calcite	Chalcedony	Dolomite	Gypsum	Rhodochrosite	Sepiolite	Siderite
Minturn and Belden Formations in the Redcliff Area								
CC43	0.56	1.14	-0.32	1.56	-1.31	-1.87	-2.02	-1.64
CC44	0.41	1.07	-0.33	1.41	-1.4	-2.52	-2.19	-1.64
CC45	-1.28	0.37	-0.48	-0.65	-3.13	-1.06	-6.78	-1.24
CC46	-1.41	0.21	-0.4	-1.02	-3.38	-3.01	-7.23	-2.8
CC47	-1.02	0.89	-0.4	0.52	-3.18	-0.86	-4.51	-1.31
CC48	-1.39	0.23	-0.4	-1.07	-3.27	-1.75	-7.52	-1.9
CC49	-1.33	0.34	-0.39	-1.06	-3.29	-1.63	-7.24	-2.66
CC50	-1.16	0.19	-0.31	-1.3	-3.29	-3.96	-6.97	-2.72
Minturn and Belden Formations in the Flat Top Area								
CC05	0.29	0.63	-0.44	1.08	-2.65	-2.8	-2.04	-2.85
CC06	0.54	1.04	-0.35	1.51	-1.46	-2.35	-1.98	-2.95
CC07	-0.2	0.78	-0.54	1.09	-2.62	-2.31	-2.6	-2.1
CC08	-0.31	0.9	-0.56	1.65	-2.85	-1.26	-1.37	-1.45
CC09	-0.22	1.15	-0.57	1.84	-2.62	-2.67	-1.06	-1.87
CC10	-0.76	0.13	-0.61	-0.22	-2.93	-1.62	-6.12	-2.25
CC11	-0.79	0.63	-0.57	0.26	-3.39	-2.9	-3.71	-2.11
Minturn and Belden Formations in the Sangre de Cristo Range								
CC13	-0.09	0.69	-0.42	1.29	-2.3	-2.29	-1.59	-1.58
CC14	-0.78	0.64	-0.59	1	-3.04	-2.18	-2.73	-1.97
CC26	0.32	0.82	-0.37	1.18	-1.4	-2.59	-2.29	-1.76
CC27	0.41	-0.18	-0.27	-0.85	-1.31	-3.43	-6.35	-2.77
CC28	0.22	1.28	-0.22	2.33	-1.6	-1.7	-0.04	-1.11
CC29	0.23	0.98	-0.26	1.57	-1.58	-0.89	-1.1	-1.16

Site	Barite	Calcite	Chalcedony	Dolomite	Gypsum	Rhodochrosite	Sepiolite	Siderite
Evaporite Facies of Eagle Valley and South Park								
CC01	0.62	1.31	-0.07	2.45	-0.68	-0.09	-0.61	-0.77
CC02	0.1	0.52	-0.02	-0.36	-2.39	-1.34	-2.96	-1.69
CC03	0.03	1.34	-0.37	2.45	-1.62	-1.13	0.2	-1.67
CC31	-0.19	0.17	-0.43	-0.15	-2.34	-1.23	-3.66	-1.03
CC33	0.33	1.14	-0.52	1.79	-1.18	-0.06	-1.61	-0.57
CC34	0.87	1.21	-0.3	1.76	-1.08	-1.89	-1.46	-1.42
CC36	0.47	1.44	-0.18	2.65	-1.02	-0.87	-0.26	-0.48
CC38	3.52	0.87	0.04	1.23	-0.31	0.31	-2.87	-1.28
CC39	0.22	0.2	-0.24	-0.1	-2.22	-3.11	-3.84	-2.37
CC40	0.29	0.58	-0.22	0.21	-0.91	-3.49	-4.36	-2.23
CC41	0.67	1.28	-0.1	2.01	-1.13	-1.01	-1.39	-0.7
Sangre de Cristo Formation in the Sangre de Cristo Range								
CC15	-1.6	-1.26	-0.37	-2.96	-4.04	-2.65	9.16	-1.86
CC16	-0.95	-0.85	-0.28	-2.46	-3.5	-2.67	-7.68	-2.88
CC17	-0.41	-0.11	-0.78	-0.9	-2.91	-2.2	-5.36	-1.03
CC18	-0.2	1.01	-0.99	1.6	-2.09	-1.01	-1.37	-1.03
CC19	0.1	0.09	-0.89	-0.33	-2.12	-2.79	-5.28	-2.59
CC20	-0.37	0.48	-0.3	0.15	-3.23	-2.29	-3.41	-2.27
CC21	-0.38	-0.47	-0.7	-1.62	-3.12	-3.07	-6.87	-2.57
CC22	-0.75	-0.56	-0.7	-1.73	-3.19	-4.6	-7.19	-3.03
CC23	-0.48	-0.16	-0.33	-1.06	-3.24	-3.46	-5.67	-2.79
CC24	-0.65	0.09	-0.4	-0.47	-3.32	-2.53	-5.1	-2.7
CC25	-0.19	0.5	-0.24	0.57	-2.97	-4.08	-3.04	-1.91
Eby and Beaver Creeks								
CC32	-1.42	-1.25	-0.46	-2.81	-3.99	-2.59	-6.58	-2.56
CC37	-1.15	0.28	-0.09	0.06	-3.18	-0.99	-4.79	-1.65



	Site 37	Site 36
pH	7.36	8.30
TDS	482.7	841.5
Calcium	84.1	141.8
Alkalinity	524	562
Sulfate	93.6	321



	Site 32	Site 31
pH	7.55	8.06
TDS	55.7	169.3
Calcium	6.8	30.1
Alkalinity	78	177
Sulfate	2.15	30.3

Figure 10. Increases in water chemistry from above to below contact with Evaporite Facies rocks of two streams. Units for conductivity in µS/cm, alkalinity in mg/L bicarbonate, and calcium and sulfate in mg/L.

Creek is underlain by Permian and Pennsylvanian Weber Sandstone and Maroon Formation and to a lesser extent by Cretaceous Dakota Sandstone and Colorado Group (Tweto, 1979). Site 37 (fig. 10) represents the stream water chemistry above the contact with Evaporite Facies rocks. Below this site the stream crosses into Evaporite Facies rocks and site 36 shows the impact of these rocks on water chemistry. TDS, pH, Ca, alkalinity, and sulfate all increase significantly. The largest increase is in sulfate (243%). The source of the sulfate is likely gypsum within the Evaporite Facies rocks. Ca concentration increases (69%), but not as much as the sulfate concentration. Congruent dissolution of gypsum would cause Ca and sulfate to increase similarly, but this is not the case. The stream water above site 37 is saturated with respect to calcite (table 9), which controls the Ca concentrations. As Ca is released by the dissolution of gypsum, much of this extra Ca is precipitated as calcite. So the increase in Ca does not keep pace with the increase in sulfate. The significant change in water chemistry between site 37 and site 36 illustrates the degradation of the waters resulting from contact with Evaporite Facies rocks and, in particular, gypsum. Increase in sulfate concentration is the main impact on the stream water chemistry. TDS values increase to a lessor extent (74%).

Upper Beaver Creek above site 32 drains areas underlain mainly by Precambrian rocks and to a lesser extent Minturn and Belden Formations rocks (Tweto, 1979). The dramatic increase in water chemistry can be seen between site 32 and site 31 after the stream comes into contact with Evaporite Facies rocks (fig.10). Again, there is a general degradation of stream water chemistry.

Within the Eagle River Valley from westward from the towns of Avon to Gypsum, significant construction of ski areas, golf courses, and houses are taking place at a rapid pace. Much of the water for snow making for the ski areas and irrigation for golf courses and homes is being obtained from tributaries of Eagle River. Much of this new construction is on Evaporite Facies rocks. The use of the water, particularly for snow making and irrigation, will probably impact the water chemistry by causing an increase in TDS in the Eagle River and the downstream Colorado River. Some of the tributaries have formed wide flat areas at their mouths before entering the Eagle River, mainly because of the presence of easily eroded Evaporite Facies rocks. These wide flat areas are ideal locations of golf courses with surrounding homes.

This land use will require large amounts of water for irrigation and has the potential to significantly impact the water quality in terms of an increase in TDS of the Eagle River and the downstream Colorado River. Irrigation of the golf courses and yards of the homes will cause chemical degradation of the Eagle River during the summer. The melting of snow made by snow making will also cause chemical degradation of the Eagle River in the spring in this area.

Summary and Conclusions

This study determines ranges and means of baseline geochemistry of stream and spring waters that evolve within each of five rock groups of Permian and Pennsylvanian rocks in western Colorado. By comparing the geochemistry of the waters that evolve in each of the five rock groups, a rationale can be developed for characterizing and ranking the rock groups as to their release of TDS (a measure of chemical weathering) and their acid-neutralizing capacities. Also, processes responsible for the control and mobility of elements in water and the potential environmental impact of development in the Eagle Valley are discussed. The following are the most significant conclusions based on these results:

- 1. The baseline geochemistry of stream and spring waters evolving in the headwater areas depends on the chemical composition of the underlying rock type. Within each rock compositional type, a unique range of water compositions evolve. Other factors such as annual precipitation, temperature, topographic setting, character of minerals (e.g., grain size and crystallinity), and biotic activity can be important, but mainly influence the rates of chemical reactions and not the type of elements present in the waters.

- 2. The waters that evolve in these five rock groups are mainly Ca^{2+}- HCO_3^- type waters, with alkaline pH values and high TDS values. Dominant species present in the water samples are Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, HCO_3^-, Cl^-, F^-, $H_4SiO_4^0$, $Al(OH)_4^-$, Fe^{2+}, and Mn^{2+}.

- 3. TDS values, which are an approximate measure of the chemical weathering rates, indicate that waters with the highest TDS values evolve from watersheds underlain by Evaporite Facies rocks in Eagle Valley and South Park. This is not surprising because these formations contain soluble evaporite minerals such as gypsum. Waters with the lowest TDS values evolve from watersheds underlain by the Sangre de Cristo Formation. These rocks contain abundant coarse grained sediments which are more resistant to weathering.

- 4. Alkalinity is a measure of the acid-neutralizing capacity of waters to introduced acidification. The waters with the highest alkalinity values are from areas underlain by Minturn and Belden Formations in the Eagle Valley, followed by Evaporite Facies in the Eagle Valley and South Park, Minturn and Belden Formations in the Redcliff area, and Minturn and Belden Formations in the Sangre de Cristo Range. The lowest alkalinity values are from areas underlain by Sangre de Cristo Formation in the Sangre de Cristo Range. All the waters contain significant alkalinity and are well buffered. The waters from the Minturn and Belden Formations and the Evaporite Facies have large capacity to neutralize acidity.

- 5. Mean values for pH of waters from areas underlain by the five rock groups are all alkaline and range from 7.82 to 8.33. The lowest mean pH values are from Belden and Minturn Formations in the Flat Tops area and the Sangre de Cristo Formation in the Sangre de Cristo Range. Both areas have large components of snow runoff which probably accounts for the lower pH values compared to the remaining rock groups.

- 6. The mean sulfate values are high compared to average fresh water from all the areas except waters from the Minturn and Beldon Formations in the Flat Tops area and the Sangre de Cristo Formation in the Sangre de Cristo Range. By far the highest sulfate values are from areas underlain by Evaporite Facies in Eagle Valley and South Park, mainly because of the presence of gypsum.

- 7. Mean concentrations of Cu, Zn, Fe, Mn, and Mn in waters from the five rock groups are low and the mean concentrations of Ni and Cr are high compared to average fresh water. Mean concentrations of U is high for all rock groups except the Sangre de Cristo Formation.

- 8. Evaporite minerals are present in the Minturn and Belden Formations in the Redcliff area, the Flat Tops areas, and Sangre de Cristo Range. The amounts vary but are generally much less than Evaporite Facies rocks.

- 9. Development of golf courses, homes, and ski areas in the Eagle Valley between Avon and Gypsum has led to the diversion of water, particularly of tributaries of the Eagle River, for irrigation and snow making. In areas where this development overlies Evaporite Faies rocks, the irrigation and snow making has probably lead to an increase in TDS and a lowering of water quality of the Eagle River and downstream Colorado River.

The unique geochemical baselines from the five rock groups demonstrates the importance of rock composition in determining the types of waters that are evolving in headwater areas. These geochemical baselines provide ranges and means of values that approximate the natural baseline geochemistry of the stream and spring waters in these watersheds for each of the five rock groups. In addition, the comparison of these geochemical baselines with future baselines will allow the recognition of any significant changes in water quality that may occur.

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Appendix 1. Chemical analyses of waters from areas underlain by Permian and Pennsylvanian rocks, western Colorado. (PPsc) Sangre de CristoFormation, (PPwm) Weber Sandstone and Maroon Formation, (Pee) Evaporitic Facies, (Pe) Eagle Valley Formation, (Pmbe) Evaporitic Facies, (Pm) Minturn Formation, (Pmb) Minturn and Belden Formations, (MDr) Missippian and Devonian rocks, and (PC) Precambirian rocks (Tweto, 1979).

Site	Latitude			Longitude			Date	Flow	Comments
	deg.	min.	sec.	deg.	min.	sec.			
Minturn and Belden Formations in the Redcliff Area									
CC05	39	32	14	106	23	26	7/19/00	3 gps	Rock Creek
CC06	39	35	52	106	25	34	7/19/00	10 gps	Game Creek
CC07	39	33	56	106	23	57	7/19/00	5 cfs	Two Elk Creek
CC08	39	31	0	106	21	43	7/19/00	10 gps	Willow Creek
CC09	39	31	23	106	20	9	7/19/00	3 cfs	Lime Creek
CC10	39	32	49	106	17	53	7/19/00	2 gps	spring from wetland
CC11	39	33	14	106	16	48	7/19/00	5gps	stream
Minturn and Belden Formations in the Flat Tops Area									
CC43	39	45	49	107	41	36	8/24/00	10 cfs	Three Forks Creek
CC44	39	45	47	107	41	34	8/24/00	10 gps	Rifle Creek
CC45	39	48	57	107	41	49	8/24/00	2 gps	G V Spring
CC46	39	47	59	107	44	47	8/24/00	2 qt/sec	spring
CC47	39	46	13	107	45	29	8/24/00	3 gps	Butler Creek
CC48	39	47	46	107	45	18	8/24/00	2 gps	spring
CC49	39	48	25	107	35	20	8/24/00	1 qt/sec	Clark Cabin Spring
CC50	39	48	19	107	35	28	8/24/00	1 qt/sec	spring
Minturn and Belden Formations in the Sangre de Cristo Range									
CC13	38	19	30	105	49	12	8/14/00	5 gps	South Prong Creek
CC14	38	19	45	105	49	35	8/14/00	2 cfs	Middle Prong Creek
CC26	38	19	2	105	45	17	8/16/00	10 cfs	Big Cottonwood Creek
CC27	38	19	4	105	45	18	8/16/00	2 qt/sec	Wolf Creek
CC28	38	9	52	105	47	34	8/17/00	10 gps	Major Creek
CC29	38	10	34	105	48	10	8/17/00	2 cfs	Garner Creek
Evaporite Facies of Eagle Valley and South Park									
CC01	39	2	5	105	58	57	7/18/00	2 qt/sec	stream
CC02	39	1	55	105	59	6	7/18/00	pump	well at campground
CC03	38	59	6	105	59	3	7/18/00	5 gps	stream
CC31	39	37	51	106	31	16	8/21/00	7 cfs	lower Beaver Creek
CC33	39	38	0	106	33	45	8/21/00	7 gps	McCoy Creek
CC34	39	39	12	106	35	5	8/21/00	10 gps	Berry Creek
CC36	39	40	8	106	49	53	8/21/00	2 cfs	lower Eby Creek
CC38	39	39	31	106	52	55	8/22/00	1 qt/sec	spring in Cottonwood Creek
CC39	39	31	54	106	55	31	8/22/00	1 gps	spring
CC40	39	29	25	106	50	5	8/22/00	1 gps	spring
CC41	39	35	10	107	3	6	8/23/00	20 gps	Cottonwood Creek

Site	Latitude			Longitude			Date	Flow	Comments
	deg.	min.	sec.	deg.	min.	sec.			
Sangre De Cristo Formation in the Sangre de Cristo Range									
CC15	37	50	52	105	26	26	8/15/00	3 cfs	Mendano Creek
CC16	37	56	26	105	27	32	8/15/00	5 gps	Music Pass Creek
CC17	37	59	42	105	29	26	8/15/00	10 cfs	South Colony Creek
CC18	38	5	41	105	38	4	8/15/00	5 cfs	upper Middle Taylor Creek
CC19	38	5	49	105	36	41	8/15/00	5 cfs	Middle Taylor Creek
CC20	38	4	49	105	33	45	8/16/00	4 gps	Alvarado Creek
CC21	38	2	17	105	32	11	8/16/00	8 cfs	Horn Creek
CC22	38	3	17	105	32	24	8/16/00	5 gps	Dry Creek
CC23	38	3	37	105	33	3	8/16/00	3 cfs	Hennequin Creek
CC24	38	8	9	105	35	35	8/16/00	1 gps	Gibson Creek
CC25	38	7	54	105	35	54	8/16/00	5 gps	Verde Creek
Eby and Beaver Creeks									
CC32	39	35	51	106	31	18	8/21/00	6 cfs	Beaver Creek
CC37	39	41	30	106	49	52	8/22/00	1 gps	Eby Creek

Appendix 1. Chemical analyses of waters from areas underlain by Permian and Pennsylvanian rocks, western Colorado. (PPsc) Sangre de CristoFormation, (PPwm) Weber Sandstone and Maroon Formation, (Pee) Evaporitic Facies, (Pe) Eagle Valley Formation, (Pmbe) Evaporitic Facies, (Pm) Minturn Formation, (Pmb) Minturn and Belden Formations, (MDr) Missippian and Devonian rocks, and (PC) Precambirian rocks (Tweto, 1979).

Site	Geology	Temperature	pH	TDS	Conductivity	Ca	Mg	Na
		Degree C		mg/L	µS/cm		mg/L	mg/L
Minturn and Belden Formations in the Redcliff Area								
CC05	Pmb	6.9	8.37	228.8	272	29.3	16.2	2.2
CC06	Pmb	7.7	8.31	426.1	564	85.6	19.4	2.3
CC07	Pmb	8.7	8.38	225.2	288	39.6	10.8	1.4
CC08	Pmb	11.3	8.57	221.0	269	32.1	16.0	1.4
CC09	Pmb	8.8	8.80	226.5	281	38.9	10.4	1.3
CC10	Pmb	14.1	7.47	260.0	314	47.3	10.2	1.3
CC11	Pmb	8.5	8.43	158.6	187	30.7	2.5	1.5
Minturn and Belden Formations in the Flat Tops Area								
CC43	Pm, MDr	7.4	8.31	479.0	633	108.2	17.6	2.0
CC44	Pm, MDr	7.8	8.31	430.9	583	95.5	14.3	2.3
CC45	Pm	10.2	7.63	270.3	333	64.6	2.0	0.9
CC46	Pm	6.1	7.51	275.0	348	66.8	2.2	0.9
CC47	Pm	9.6	8.06	313.8	377	73.3	3.1	1.3
CC48	Pm	6.6	7.46	297.3	355	71.7	1.9	1.0
CC49	Pmb	6.2	7.65	271.6	329	65.2	1.1	1.2
CC50	Pmb	4.3	7.66	228.0	296	58.0	1.2	1.3
Minturn and Belden Formations in the Sangre de Cristo Range								
CC13	Pmb	13.4	8.37	235.0	301	31.9	17.2	3.3
CC14	Pmb	12.6	8.32	196.5	235	30.5	10.6	1.3
CC26	Pmb	12	8.18	405.6	532	79.9	19.0	3.5
CC27	Pmb	7.9	7.11	469.0	632	90.6	24.4	4.7
CC28	Pm	10.7	8.56	444.9	552	72.0	30.3	4.5
CC29	Pm	14	8.38	356.0	473	67.0	17.2	3.3
Evaporite Facies of Eagle Valley and South Park								
CC01	Pmbe	23.3	8.01	1262.9	1416	212.9	67.3	59.9
CC02	Pmbe	7.5	7.97	281.6	370	50.0	8.8	6.4
CC03	Pmbe	22.5	8.65	362.0	462	66.5	18.0	6.0
CC31	Pee, Pm, pC	11.7	8.06	169.3	232	30.1	7.0	3.8
CC33	Pee, Pm	13.6	8.43	492.6	904	104.7	21.2	4.3
CC34	Pe, PPm	12.8	8.36	563.2	720	125.6	17.9	3.9
CC36	Pee, PPwm, others	18.4	8.30	841.5	994	141.8	45.2	31.7
CC38	Pee	14.3	7.49	1757.3	2020	387.2	73.7	28.6
CC39	Pee	6.7	7.87	232.1	292	39.4	11.1	2.7
CC40	Pee	6	7.72	638.7	864	154.6	15.6	3.1
CC41	Pee	13.5	8.14	675.5	841	142.4	26.1	5.7

Site	Geology	Temperature	pH	TDS	Conductivity	Ca	Mg	Na
		Degree C		mg/L	µS/cm		mg/L	mg/L
Sangre De Cristo Formation in the Sangre de Cristo Range								
CC15	PPsc	10.4	7.54	58.3	63	6.9	1.9	1.8
CC16	PPsc, Pm	13	7.13	123.2	147	21.1	2.5	2.5
CC17	PPsc	12.9	8.10	98.8	126	17.5	2.4	1.3
CC18	PPsc, Pmb	16.3	8.99	167.5	237	32.3	7.2	1.2
CC19	PPsc, Pmb	11.8	8.01	169.0	234	32.0	7.0	1.4
CC20	PPsc, Pmb	9.8	8.18	180.8	216	33.7	4.0	3.9
CC21	PPsc	9.6	7.65	110.0	140	19.7	3.2	1.2
CC22	PPsc	11.8	7.53	110.1	142	19.1	3.4	1.0
CC23	PPsc	7.9	7.63	165.4	208	31.0	4.7	2.1
CC24	PPsc	12.8	7.73	181.3	223	34.0	5.1	2.5
CC25	PPsc	10.9	8.01	246.1	294	39.4	10.6	5.7
Eby and Beaver Creeks								
CC32	Pm, pC	11.5	7.55	55.7	67	6.8	2.4	1.4
CC37	PPwm	9.5	7.36	482.7	593	84.1	20.5	12.4

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Site	K	Si	Alkalinity	SO_4	Cl	F	N	Al
	mg/L	mg/L	mg/L HCO_3	mg/L	mg/L	mg/L	mg/L	µg/L
Minturn and Belden Formations in the Redcliff Area								
CC05	1.13	3.7	324	16.3	<1	<0.05	<0.05	3.21
CC06	0.89	4.7	393	119	<1	0.05	<0.05	4.85
CC07	0.53	3.1	317	13.1	<1	<0.05	<0.05	2.70
CC08	0.61	3.3	319	9.94	<1	<0.05	<0.05	7.39
CC09	0.51	3.0	320	14.3	<1	<0.05	0.08	3.90
CC10	<0.5	3.1	389	5.80	<1	<0.05	0.08	2.09
CC11	<0.5	2.9	239	2.46	<1	<0.05	<0.05	2.89
Minturn and Belden Formations in the Flat Tops Area								
CC43	0.52	5.0	412	143	<1	0.10	0.33	2.23
CC44	0.55	4.9	383	124	1.14	0.08	0.26	2.04
CC45	<0.5	3.7	398	2.60	<1	<0.05	0.34	1.52
CC46	<0.5	3.9	405	1.39	<1	<0.05	0.87	0.90
CC47	<0.5	4.4	465	2.20	<1	0.06	<0.05	1.23
CC48	<0.5	4.0	440	1.74	<1	<0.05	0.45	1.80
CC49	<0.5	4.0	402	1.74	<1	<0.05	<0.05	1.95
CC50	<0.5	4.6	326	1.83	<1	<0.05	0.49	1.39
Minturn and Belden Formations in the Sangre de Cristo Range								
CC13	0.64	4.7	285	36.3	<1	0.07	<0.05	6.29
CC14	0.91	3.1	291	6.22	<1	<0.05	<0.05	1.74
CC26	1.30	5.1	295	151	1.03	0.13	0.07	1.20
CC27	1.20	5.6	350	169	1.25	0.12	<0.05	0.88
CC28	1.36	7.0	444	110	1.10	0.08	<0.05	4.07
CC29	3.16	7.0	294	113	<1	0.15	<0.05	2.78
Evaporite Facies of Eagle Valley and South Park								
CC01	5.61	13.7	538	615	24.0	0.9	<0.05	4.26
CC02	0.83	9.8	373	18.6	3.79	0.16	<0.05	2.61
CC03	0.97	7.2	307	111	1.30	0.09	<0.05	7.20
CC31	0.95	4.4	177	30.3	5.74	<0.05	0.27	8.21
CC33	1.23	3.8	281	216	3.18	0.07	<0.05	5.46
CC34	0.94	6.1	342	239	1.36	<0.05	0.18	0.98
CC36	3.27	9.6	562	321	12.4	0.2	<0.05	2.07
CC38	2.83	13.8	525	972	21.3	0.1	<0.05	1.38
CC39	<0.5	5.8	283	32.9	<1	<0.05	0.11	1.08
CC40	<0.5	5.9	347	288	<1	0.05	0.19	0.88
CC41	1.91	9.8	575	204	2.90	0.08	<0.05	5.53

Site	K	Si	Alkalinity	SO_4	Cl	F	N	Al
	mg/L	mg/L	mg/L HCO_3	mg/L	mg/L	mg/L	mg/L	µg/L
Sangre De Cristo Formation in the Sangre de Cristo Range								
CC15	0.50	4.8	81	1.84	<1	0.14	<0.05	11.1
CC16	<0.5	6.4	177	2.59	<1	0.07	<0.05	2.51
CC17	<0.5	2.0	128	11.7	<1	<0.05	<0.05	6.43
CC18	<0.5	1.5	141	54.9	<1	<0.05	<0.05	3.94
CC19	<0.5	1.5	158	48.3	<1	<0.05	<0.05	1.33
CC20	<0.5	5.6	263	3.39	<1	<0.05	<0.05	1.52
CC21	<0.5	2.2	155	6.46	<1	<0.05	0.07	2.00
CC22	<0.5	2.3	158	5.67	<1	<0.05	<0.05	0.22
CC23	0.51	4.9	240	3.49	<1	<0.05	<0.05	0.49
CC24	0.55	4.8	266	2.78	<1	<0.05	<0.05	1.01
CC25	0.57	6.6	359	6.03	<1	<0.05	<0.05	0.48
Eby and Beaver Creeks								
CC32	<0.5	4.0	78	2.15	<1	<0.05	<0.05	11.9
CC37	2.05	8.8	524	93.6	3.05	0.17	<0.05	1.24

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Site	Fe	Mn	P	Li ug/L	Sc ug/L	Ti ug/L	V ug/L	Cr ug/L
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Minturn and Belden Formations in the Redcliff Area								
CC05	0.002	0.1	<0.01	4.1	0.9	< 0.1	0.3	< 1
CC06	0.002	0.3	<0.01	3.7	1.1	1.3	0.4	< 1
CC07	<0.001	0.3	<0.01	2.4	0.7	< 0.1	0.3	1.0
CC08	0.002	2.8	<0.01	2.8	0.7	0.1	0.3	< 1
CC09	<0.001	0.1	<0.01	2.1	0.6	0.1	0.3	< 1
CC10	0.002	4.2	<0.01	2.0	0.6	< 0.1	0.3	1.0
CC11	<0.001	0.08	<0.01	1.3	0.6	< 0.1	0.4	< 1
Minturn and Belden Formations in the Flat Tops Area								
CC43	0.002	0.9	<0.01	2.8	1.1	2.1	1.1	2.8
CC44	0.002	0.2	<0.01	2.9	1.1	1.8	1.0	2.3
CC45	0.014	12.7	<0.01	0.3	0.8	0.2	1.7	2.4
CC46	<0.001	0.2	0.019	0.5	0.8	< 0.1	1.4	2.5
CC47	0.005	10.3	0.011	0.8	0.9	< 0.1	2.1	2.4
CC48	0.005	3.8	0.016	0.3	0.8	< 0.1	1.7	2.8
CC49	<0.001	3.7	0.014	0.3	0.9	< 0.1	2.5	2.6
CC50	<0.001	0.02	0.018	0.3	0.9	< 0.1	2.6	2.1
Minturn and Belden Formations in the Sangre de Cristo Range								
CC13	0.002	0.3	<0.01	4.1	1.0	0.8	0.4	3.2
CC14	0.001	0.4	<0.01	1.0	0.7	0.4	0.7	1.0
CC26	0.002	0.2	<0.01	4.0	1.1	4.5	0.4	< 1
CC27	0.002	0.2	<0.01	4.5	1.1	2.2	0.4	< 1
CC28	0.004	1.0	0.017	1.4	1.5	1.4	0.7	1.0
CC29	0.005	7.6	0.019	0.5	1.4	1.6	0.6	< 1
Evaporite Facies of Eagle Valley and South Park								
CC01	0.016	57.2	<0.01	110	2.8	7.6	0.9	1.7
CC02	0.003	4.4	<0.01	1.3	2.0	< 0.1	2.1	1.6
CC03	0.002	3.2	<0.01	1.4	1.5	1.2	3.2	< 1
CC31	0.015	6.3	<0.01	5.9	1.0	0.3	0.4	< 1
CC33	0.019	12.9	<0.01	7.9	1.0	3.4	0.4	< 1
CC34	0.003	0.8	<0.01	2.4	1.4	3.5	2.7	< 1
CC36	0.019	7.1	<0.01	18.1	2.2	5.2	1.8	1.2
CC38	0.020	441	<0.01	16.8	3.4	15.3	0.7	1.0
CC39	0.001	0.1	0.030	< 0.1	1.6	0.4	2.8	< 1
CC40	0.002	0.06	0.011	1.2	1.4	4.2	1.1	< 1
CC41	0.016	6.3	0.023	6.7	2.0	2.8	2.7	3.8

Site	Fe	Mn	P	Li ug/L	Sc ug/L	Ti ug/L	V ug/L	Cr ug/L
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Sangre De Cristo Formation in the Sangre de Cristo Range								
CC15	0.012	1.0	<0.01	0.6	0.8	0.5	0.4	< 1
CC16	0.002	1.2	0.013	1.0	1.2	0.5	1.0	< 1
CC17	0.016	0.7	<0.01	0.8	0.4	0.6	0.3	< 1
CC18	0.004	4.4	<0.01	1.1	0.4	1.1	0.2	< 1
CC19	<0.001	0.2	<0.01	1.1	0.4	1.0	0.2	< 1
CC20	<0.001	0.4	<0.01	1.6	1.1	0.3	0.4	< 1
CC21	0.001	0.2	<0.01	1.0	0.4	0.4	0.2	< 1
CC22	<0.001	< 0.01	<0.01	0.6	0.5	< 0.1	1.6	5.7
CC23	<0.001	0.07	<0.01	1.2	1.0	1.3	0.3	< 1
CC24	<0.001	0.4	<0.01	0.8	1.0	0.8	0.5	< 1
CC25	0.002	< 0.01	<0.01	3.4	1.4	< 0.1	3.8	14.0
Eby and Beaver Creeks								
CC32	0.024	1.1	<0.01	0.4	0.9	0.1	0.1	< 1
CC37	0.009	22.8	<0.01	18.1	1.9	1.2	1.5	1

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Site	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo
	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Minturn and Belden Formations in the Redcliff Area										
CC05	0.04	0.8	0.63	0.7	0.54	81.0	0.04	< 0.05	< 0.02	0.62
CC06	0.08	2.1	0.53	0.6	0.37	597	0.12	< 0.05	< 0.02	0.85
CC07	0.05	1.2	< 0.5	< 0.5	0.31	98.4	0.03	< 0.05	0.03	1.29
CC08	0.06	1.0	< 0.5	< 0.5	0.27	61.0	0.03	0.05	0.03	0.42
CC09	0.05	1.1	< 0.5	< 0.5	0.32	85.4	0.02	< 0.05	0.03	0.31
CC10	0.07	1.4	< 0.5	< 0.5	0.30	86.2	0.01	< 0.05	0.03	0.31
CC11	0.04	0.9	< 0.5	< 0.5	0.35	52.6	0.03	< 0.05	0.02	< 0.2
Minturn and Belden Formations in the Flat Tops Area										
CC43	0.10	2.9	0.57	0.6	0.50	1030	0.10	< 0.05	< 0.02	2.21
CC44	0.09	2.5	0.50	< 0.5	0.33	1040	0.10	< 0.05	< 0.02	2.16
CC45	0.11	1.6	< 0.5	< 0.5	0.57	53.6	0.03	< 0.05	< 0.02	0.42
CC46	0.06	1.6	< 0.5	< 0.5	0.34	53.4	0.02	< 0.05	< 0.02	< 0.2
CC47	0.09	2.0	< 0.5	< 0.5	0.77	98.3	0.02	< 0.05	< 0.02	0.50
CC48	0.07	1.7	< 0.5	< 0.5	0.57	55.4	0.03	< 0.05	< 0.02	< 0.2
CC49	0.07	1.6	< 0.5	< 0.5	0.29	67.6	0.07	< 0.05	< 0.02	< 0.2
CC50	0.06	1.4	< 0.5	< 0.5	0.35	59.9	0.02	< 0.05	< 0.02	< 0.2
Minturn and Belden Formations in the Sangre de Cristo Range										
CC13	0.04	1.0	< 0.5	18.6	0.23	198	0.01	< 0.05	< 0.02	0.53
CC14	0.03	0.9	< 0.5	0.8	0.37	120	0.01	< 0.05	< 0.02	0.79
CC26	0.07	2.3	0.50	0.6	0.90	1230	0.10	0.06	0.06	2.38
CC27	0.09	2.6	0.53	0.5	0.64	1310	0.12	< 0.05	0.02	2.75
CC28	0.09	2.2	0.86	0.7	0.73	506	0.13	< 0.05	< 0.02	1.80
CC29	0.09	2.1	0.60	0.5	1.48	572	0.10	0.05	< 0.02	8.06
Evaporite Facies of Eagle Valley and South Park										
CC01	0.30	6.0	1.7	2	8.43	3110	0.14	0.3	< 0.02	0.71
CC02	0.08	1.6	2.2	123	0.23	363	0.03	< 0.05	< 0.02	0.46
CC03	0.07	1.6	0.55	0.6	0.35	828	0.16	< 0.05	< 0.02	1.90
CC31	0.06	1.1	1.4	0.9	0.64	229	0.05	0.06	< 0.02	0.74
CC33	0.13	3.5	1.3	7.0	0.89	1280	0.11	0.05	< 0.02	1.71
CC34	0.13	3.9	0.79	0.7	0.32	1690	0.11	< 0.05	< 0.02	3.25
CC36	0.21	5.1	1.1	1	0.75	2670	0.11	0.2	< 0.02	6.86
CC38	3.00	14.4	2.3	2.3	1.00	4720	0.13	0.2	< 0.02	8.62
CC39	0.04	1.2	< 0.5	< 0.5	0.27	215	0.01	< 0.05	< 0.02	0.83
CC40	0.14	4.5	0.77	1	0.38	1270	0.10	< 0.05	< 0.02	2.50
CC41	0.22	4.2	0.91	0.8	0.59	1340	0.14	0.08	< 0.02	2.39

Site	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo
	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Sangre De Cristo Formation in the Sangre de Cristo Range										
CC15	0.03	0.3	0.62	1	0.42	36.4	0.09	0.06	< 0.02	0.47
CC16	0.04	0.6	< 0.5	< 0.5	0.24	79.9	0.03	< 0.05	0.02	< 0.2
CC17	0.03	0.6	0.52	< 0.5	0.23	86.7	0.03	< 0.05	< 0.02	< 0.2
CC18	0.05	1.0	< 0.5	< 0.5	0.28	279	0.01	< 0.05	< 0.02	0.41
CC19	0.04	1.0	< 0.5	< 0.5	0.26	259	0.01	< 0.05	< 0.02	0.30
CC20	0.04	0.9	< 0.5	< 0.5	0.20	145	0.02	< 0.05	< 0.02	< 0.2
CC21	0.03	0.7	0.54	< 0.5	0.42	86.5	0.03	< 0.05	< 0.02	< 0.2
CC22	0.03	0.6	< 0.5	< 0.5	0.38	81.8	0.02	0.1	0.1	0.46
CC23	0.03	0.8	< 0.5	< 0.5	0.52	132	0.01	< 0.05	0.04	< 0.2
CC24	0.05	1.0	< 0.5	< 0.5	0.27	91.6	0.02	< 0.05	0.02	< 0.2
CC25	0.04	1.2	< 0.5	< 0.5	0.53	364	0.08	0.1	0.1	1.38
Eby and Beaver Creeks										
CC32	0.0	0.3	< 0.5	0.80	0.44	34.30	0.08	0.05	< 0.02	< 0.2
CC37	0.13	3	0.6	0.5	0.54	1180	0.11	0.08	< 0.02	3.85

Appendix 1. Chemical analyses of waters from areas underlain by Permian and Pennsylvanian rocks, western Colorado. (PPsc) Sangre de CristoFormation, (PPwm) Weber Sandstone and Maroon Formation, (Pee) Evaporitic Facies, (Pe) Eagle Valley Formation, (Pmbe) Evaporitic Facies, (Pm) Minturn Formation, (Pmb) Minturn and Belden Formations, (MDr) Missippian and Devonian rocks, and (PC) Precambirian rocks (Tweto, 1979).

Site	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Tb
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Minturn and Belden Formations in the Redcliff Area										
CC05	< 0.1	< 0.01	167	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.005
CC06	< 0.1	< 0.01	65.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.005
CC07	0.1	< 0.01	73.6	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.008	< 0.005
CC08	< 0.1	< 0.01	86.3	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.008	< 0.005
CC09	< 0.1	< 0.01	66.0	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.008	< 0.005
CC10	< 0.1	< 0.01	62.0	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.005
CC11	< 0.1	< 0.01	85.8	0.01	< 0.01	< 0.01	0.02	< 0.01	0.01	< 0.005
Minturn and Belden Formations in the Flat Tops Area										
CC43	< 0.1	< 0.01	60.4	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC44	< 0.1	< 0.01	47.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC45	< 0.1	< 0.01	34.6	0.01	0.03	< 0.01	0.01	< 0.01	0.007	< 0.005
CC46	< 0.1	< 0.01	39.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005
CC47	< 0.1	< 0.01	76.4	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.005
CC48	< 0.1	< 0.01	34.4	0.01	0.02	< 0.01	0.01	< 0.01	0.006	< 0.005
CC49	< 0.1	< 0.01	37.8	0.03	0.02	< 0.01	0.03	< 0.01	0.007	< 0.005
CC50	< 0.1	< 0.01	44.7	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.005	< 0.005
Minturn and Belden Formations in the Sangre de Cristo Range										
CC13	< 0.1	< 0.01	46.9	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC14	< 0.1	< 0.01	47.0	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC26	< 0.1	< 0.01	39.6	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC27	0.2	< 0.01	38.2	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.005	< 0.005
CC28	< 0.1	< 0.01	39.6	< 0.01	0.02	< 0.01	0.01	< 0.01	0.005	< 0.005
CC29	< 0.1	< 0.01	42.8	< 0.01	0.01	< 0.01	0.02	< 0.01	< 0.005	< 0.005
Evaporite Facies of Eagle Valley and South Park										
CC01	< 0.1	< 0.01	71.6	< 0.01	0.02	< 0.01	0.02	< 0.01	0.009	< 0.005
CC02	< 0.1	< 0.01	104	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.005
CC03	< 0.1	< 0.01	40.1	0.02	0.05	< 0.01	0.02	< 0.01	0.007	< 0.005
CC31	< 0.1	< 0.01	36.1	0.03	0.03	0.01	0.04	0.01	0.007	< 0.005
CC33	< 0.1	< 0.01	53.4	0.02	0.03	< 0.01	0.03	< 0.01	0.007	< 0.005
CC34	< 0.1	< 0.01	116	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.005
CC36	0.1	< 0.01	55.3	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.005
CC38	< 0.1	< 0.01	34.2	0.01	0.03	< 0.01	< 0.01	< 0.01	0.005	< 0.005
CC39	< 0.1	< 0.01	72.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.005
CC40	< 0.1	< 0.01	19.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.005	< 0.005
CC41	< 0.1	< 0.01	92.7	0.01	0.03	< 0.01	0.02	< 0.01	0.01	< 0.005

Site	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Tb
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Sangre De Cristo Formation in the Sangre de Cristo Range										
CC15	< 0.1	< 0.01	14.8	0.05	0.04	0.01	0.06	< 0.01	0.005	< 0.005
CC16	< 0.1	< 0.01	64.2	0.01	0.01	< 0.01	0.01	< 0.01	0.007	< 0.005
CC17	< 0.1	< 0.01	48.2	0.02	0.02	< 0.01	0.02	0.01	0.007	< 0.005
CC18	< 0.1	< 0.01	25.8	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005
CC19	< 0.1	< 0.01	46.3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.007	< 0.005
CC20	< 0.1	< 0.01	180	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.02	< 0.005
CC21	< 0.1	< 0.01	80.1	0.01	< 0.01	< 0.01	0.02	< 0.01	0.01	< 0.005
CC22	0.1	< 0.01	43.5	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.005
CC23	< 0.1	0.01	121	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.005
CC24	< 0.1	< 0.01	136	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.005
CC25	0.64	< 0.01	186	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.005
Eby and Beaver Creeks										
CC32	< 0.1	< 0.01	20.40	0.11	0.04	0.03	0.1	0.02	0.01	< 0.005
CC37	< 0.1	< 0.01	66.7	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.008	< 0.005

Appendix 1. Chemical analyses of waters from areas underlain by Permian and Pennsylvanian rocks, western Colorado. (PPsc) Sangre de CristoFormation, (PPwm) Weber Sandstone and Maroon Formation, (Pee) Evaporitic Facies, (Pe) Eagle Valley Formation, (Pmbe) Evaporitic Facies, (Pm) Minturn Formation, (Pmb) Minturn and Belden Formations, (MDr) Missippian and Devonian rocks, and (PC) Precambirian rocks (Tweto, 1979).

Site	Gd	Dy	Ta	W	Pb	Bi	Th	U
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Minturn and Belden Formations in the Redcliff Area								
CC05	0.01	0.009	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	2.13
CC06	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	1.18
CC07	0.005	< 0.005	0.04	0.06	< 0.05	0.06	0.01	1.43
CC08	0.005	< 0.005	0.04	0.06	< 0.05	0.02	0.01	1.04
CC09	< 0.005	< 0.005	0.04	0.06	< 0.05	0.01	0.008	1.23
CC10	< 0.005	< 0.005	0.03	0.05	< 0.05	0.008	0.008	1.43
CC11	0.005	< 0.005	0.03	0.02	< 0.05	< 0.005	< 0.005	1.41
Minturn and Belden Formations in the Flat Tops Area								
CC43	< 0.005	< 0.005	< 0.02	0.02	< 0.05	< 0.005	0.005	1.93
CC44	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	2.40
CC45	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	1.09
CC46	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.49
CC47	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.97
CC48	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.36
CC49	0.005	0.005	< 0.02	< 0.02	< 0.05	< 0.005	0.005	0.57
CC50	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.38
Minturn and Belden Formations in the Sangre de Cristo Range								
CC13	< 0.005	< 0.005	0.02	0.03	< 0.05	< 0.005	0.005	1.25
CC14	< 0.005	< 0.005	0.03	0.04	< 0.05	< 0.005	< 0.005	1.19
CC26	< 0.005	< 0.005	0.05	0.07	< 0.05	< 0.005	0.02	1.00
CC27	< 0.005	< 0.005	0.05	0.07	< 0.05	0.05	0.03	1.26
CC28	< 0.005	< 0.005	0.04	0.07	< 0.05	0.02	0.02	1.81
CC29	< 0.005	< 0.005	0.03	0.08	< 0.05	0.009	0.03	1.24
Evaporite Facies of Eagle Valley and South Park								
CC01	< 0.005	< 0.005	0.06	0.07	< 0.05	< 0.005	0.05	1.16
CC02	< 0.005	< 0.005	< 0.02	< 0.02	0.1	< 0.005	< 0.005	1.69
CC03	0.008	0.009	< 0.02	< 0.02	< 0.05	< 0.005	0.005	1.62
CC31	0.008	0.007	< 0.02	0.04	< 0.05	< 0.005	0.007	0.37
CC33	0.009	0.006	< 0.02	0.04	0.08	< 0.005	0.03	1.45
CC34	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	0.02	1.93
CC36	< 0.005	< 0.005	< 0.02	0.03	< 0.05	< 0.005	0.04	6.12
CC38	< 0.005	< 0.005	< 0.02	0.03	< 0.05	< 0.005	0.14	4.57
CC39	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.44
CC40	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	0.008	1.04
CC41	0.006	0.006	0.03	0.04	< 0.05	< 0.005	0.01	1.45

Site	Gd	Dy	Ta	W	Pb	Bi	Th	U
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Sangre De Cristo Formation in the Sangre de Cristo Range								
CC15	0.02	0.01	0.03	0.03	< 0.05	< 0.005	0.01	0.03
CC16	0.006	< 0.005	0.03	< 0.02	< 0.05	< 0.005	0.007	0.20
CC17	0.007	0.005	0.02	0.02	< 0.05	< 0.005	0.006	0.32
CC18	< 0.005	< 0.005	< 0.02	0.02	< 0.05	< 0.005	0.007	0.48
CC19	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.28
CC20	< 0.005	< 0.005	< 0.02	0.03	< 0.05	< 0.005	< 0.005	0.25
CC21	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	< 0.005	0.43
CC22	< 0.005	< 0.005	0.08	0.51	< 0.05	< 0.005	0.007	0.21
CC23	< 0.005	< 0.005	0.03	0.05	< 0.05	< 0.005	< 0.005	0.62
CC24	< 0.005	< 0.005	0.03	< 0.02	< 0.05	< 0.005	< 0.005	1.59
CC25	< 0.005	< 0.005	0.09	0.44	< 0.05	< 0.005	< 0.005	1.94
Eby and Beaver Creeks								
CC32	0.02	0.01	< 0.02	< 0.02	< 0.05	< 0.005	0.008	0.06
CC37	< 0.005	< 0.005	< 0.02	< 0.02	< 0.05	< 0.005	0.009	2.42