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Geochemical Baselines and Maps Showing Acid-Neutralizing Capacity and Potential Release of Total Dissolved Solids of Stream and Spring Waters from Different Rock Compositional Types from Mountainous Watersheds in the Gunnison, Uncompahgre, and Grand Mesa National Forest, Colorado

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U.S. DEPARTMENT OF THE INTERIOR
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Introduction

When precipitation, as rain and snow, falls within a mountainous watershed, water comes into contact with rock minerals and chemical weathering is initiated. Chemical weathering involves the congruent dissolution of minerals such as calcite or the incongruent dissolution and transformation of minerals such as plagioclase to clay minerals. These chemical weathering 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. In addition, generally minor input can come from atmospheric precipitation or dry fall. Biota activity in the soil zone concentrates CO_2, and biota may concentrate or consume species. Other factors such as rates of mechanical erosion, the grain size and crystallinity of the rock minerals, amount and distribution of precipitation, temperature, and type and amount of vegetation 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. The major element composition of most rock types are generally known from geologic maps, giving insight into the expected major element composition of natural waters of the basin in question. The is not true with respect to trace elements which can vary two or more orders of magnitude within similar rock types.

This background geochemistry of the natural waters of a basin can be modified by input from anthropogenic processes such as nuclear fallout, atmospheric emission, or mining wastes. There is probably no place in the world in which the natural background composition of waters of an area has not been modified to some extent by anthropogenic processes; the effects of these processes are always superimposed on the natural background geochemistry. But areas, particularly mountainous headwater areas, can be selected which are only minimally affected by anthropogenic input. Headwaters areas are the highest and the most remote regions of a watershed. It is where waters are imprinted by the chemical composition of the rocks which underlie the watershed. Many of these headwater areas are critical to water resource development. These areas have comparatively high precipitation and low evapotranspiration rates and generally lack extensive groundwater reservoirs, due to shallow soils and extensive outcroppings of bedrock. The distribution of water available in streams in these mountainous headwater areas are uneven throughout the year 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. Mountainous headwaters react quickly to changes in input and are especially vulnerable to anthropogenic impact.

Geochemical baselines, at a particular point in time for stream and spring waters, can be determined in these mountainous headwaters, and may approximate the natural background geochemistry. This information is useful for an understanding of the processes responsible for the chemical composition of waters of a watershed. In addition, because water geochemistry is sensitive to changes in the environment, by monitoring water geochemistry in these mountainous headwater areas and comparing the results to the earlier baseline data, changes in the environment within the basin can be determined. This geochemical baseline is an approximation of the natural background and if remediation is needed in the future because of anthropogenic contamination, this baseline is the ideal goal. Note that it is not feasible to require geochemical quality standards lower than this natural baseline.

The purpose of this study is to determine for different rock compositional types, the range of species and other geochemical parameters and characterize the baseline geochemistry of stream and spring waters evolving within mountainous watersheds within three National Forests in western Colorado. The ranges of species and other parameters are determined for each of the major rock compositional types in the Gunnison, Uncompahgre, and Grand Mesa National Forests (GMUG) and spacial maps of mean pH values, potential release of total dissolved solids, and acid-neutralizing capacity were determined for each of the National Forests. In addition, processes responsible for the control and mobility of the elements in the natural waters were investigated. These geochemical baselines demonstrate the importance of rock composition in determining the types of waters evolving in these headwater areas, and will also allow the recognition of any significant changes in water quality that may occur in the future in these mountainous headwater areas.

Study Area

The study area is located in Western Colorado and includes the Gunnison, Uncompahgre, and Grand Mesa National Forests (fig. 1). The eastern part of the study area occurs within the Southern Rocky Mountains and the western part occurs in the Colorado Plateau 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. Uncompahgre Peak at 14,390 feet is the highest point in the study area. The lowest point is along the western flank of Battlement Mesa at around 6000 feet. The main river systems that drain the area are the Uncompahgre-Gunnison Rivers and the San Miguel-Dolores Rivers. Both river systems drain into the Colorado River after leaving the study area. Annual precipitation ranges from around 20 inches in the northwestern part of the study area to more than 50 inches (Colorado Climate Center, 1984). The higher elevations receive the highest

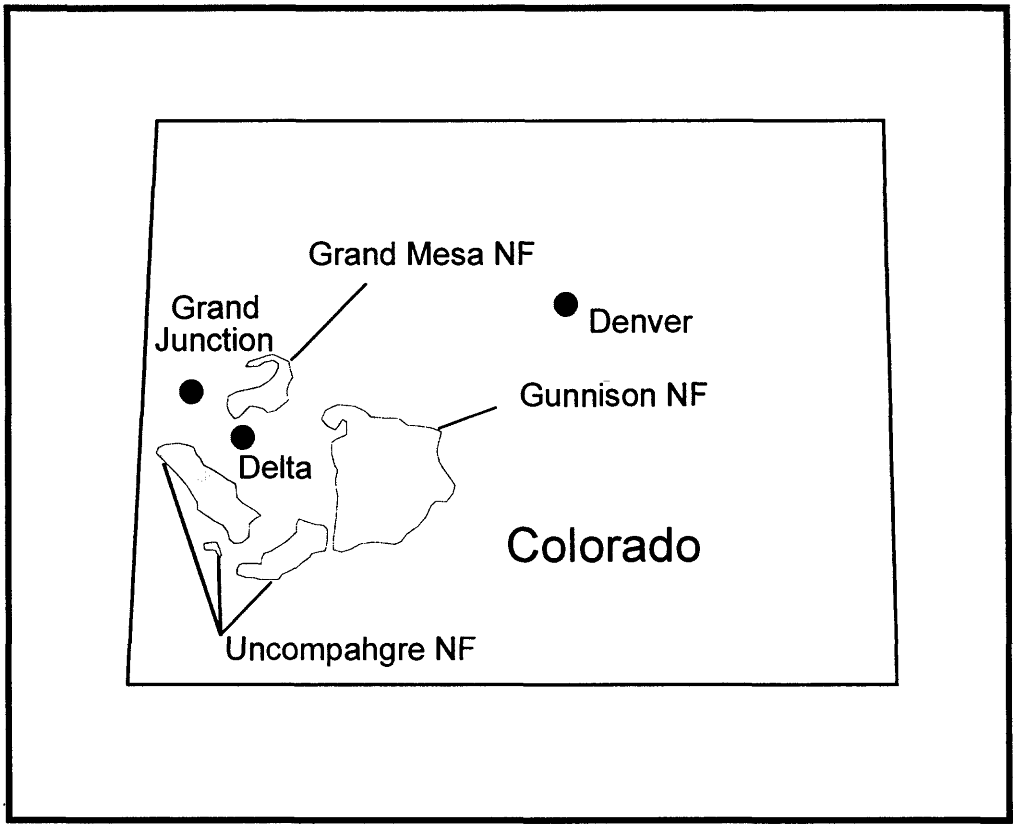

Figure 1. Map showing locations of the three National Forests.

precipitation, mainly as snow during the winter. Winter weather is influenced by storm systems originating from the Pacific Ocean. Snow pack above 10,000 feet begins to accumulate in late October and reaches a maximum in mid-April (Benedic, 1991). In summer, particularly July, August, and early September, moist air from the Gulf of Mexico leads to afternoon thunderstorms and storm runoff. Snowmelt runoff usually runs 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. Mean annual temperature varies from around 32 degrees in the highest elevations to above 50 degrees in the lower elevations (Benci and McKee, 1977). The natural vegetation in the study area is strongly zoned by altitude and is divided into six general groups based on the classification of the U.S. Dept. of Agriculture (1972). Except for grasslands which can occur in both higher and lower elevations, the groups from the highest to the lowest elevation are: 1) alpine tundra, 2) subalpine forest, 3) pinyon pine-juniper forest, 4) oak scrubland, 5) sagebrush scrubland, and 6) grassland. Timberline is around 11,000 feet, but varies as a function of slope orientation to sun, rock/soil cover, and other effects.

Geology

Bedrock geology in the three National Forests ranges from Proterozoic metamorphic and crystalline rocks to Quaternary sediments (Table 1). Major rock types within the Grand Mesa National Forest (fig. 2) include Pliocene to Miocene basalt flows and associated tuff, breccia, and conglomerate of late volcanic bimodal suite, which occurs along the top of Grand Mesa, Eocene Green River Formation of marlstone, sandstone, and oil shale, Uinta Formation of sandstone and siltstone, and Eocene to Paleocene Wasatch and Ohio Creek Formations of claystone, mudstone, sandstone, and conglomerate. These Tertiary sedimentary rocks occur mainly along the flanks of Grand Mesa and the top and flanks of Battlement Mesa.

The major rock types of the Uncompahgre National Forest (fig. 3) consist of Pliocene to Miocene basalt flows and associated tuff, breccia, and conglomerate, Oligocene ash-flow tuff, Oligocene inter-ash flow quartz latitic lava and breccia, Oligocene andesitic lava and breccia, Cretaceous Mancos Shale, Cretaceous and Jurassic Dakota, Purgatoire, and Morrison Formations of sandstone, shale, claystone, and conglomerate, Jurassic Morrison and Summerville Formations, and Entrada Sandstone of claystone, sandstone, mudstone, shale, siltstone, and limestone, Triassic and Permian Windgate Sandstone, Chinle Formation, and Dolores Formation of siltstone, sandstone and conglomerate, Permian Cutler Formation of arkosic sandstone, siltstone, and conglomerate, Pennsylvanian Hermosa Formation of arkosic sandstone,

Table 1. Generalized stratigraphic column of dominant rocks in the Grand Mesa, Uncompahgre, and Gunnison National Forests

Period	Epoch	Rock Unit or Type	Domiant Lithology
Quaternary	Holocene and Pleistoc	alluvium, colluvium, glacial, and landslide deposits	silt, sand, clay, gravel, boulders
Tertiary	Pliocene and Miocene	basalt flows and associated rocks	lava flows, tuff, breccia, and conglomerate
Tertiary	Oligocene	ash-flow tuff	rhyolitic ash-flow tuff
Tertiary	Oligocene	quartz latitic lava and breccia	latitic lava and breccia
Tertiary	Oligocene	andesitic lava and associated rocks	andesitic lava, breccia, tuff, and conglomerate
Tertiary	Eocene and Oligocene	intrusive stocks and dikes	felsic and intermediate composition plutonic rock
Tertiary	Eocene	Uinta Formation	sandstone and siltstone
Tertiary	Eocene	Green River Formation	marlstone, sandstone, siltstone, and oil shale
Tertiary	Eocene	Wasatch Formation and Ohio Creek Formation	claystone, modstone, sandstone, and conglomerate
Cretaceous	Late	Mesavede Group	mudstone, shale, coal, and sandstone
Cretaceous	Late	Mancos Shale	shale and calcareous shale with sandstone
Cretaceous	Early	Dakoka Ss, Burro Canyon Fm	sandstone, shale, conglomerate, and thin coal beds
Jurassic	Late	Morrison Fm, Summerville Fm	siltstone and mudstone with lens of sandstone and lime
Jurassic	Middle	Entrada Sandstone	sandstone
Triassic and Permian		Wingate Ss, Chinle Fm, Dolores Fm	siltstone, sandstone,and limestone
Permian and Pennsyvanian		Cutler Fm, Maroon Fm, Minturn Fm, Belden Fm, Hermosa Fm	arkosic sandstone, siltstone, conglomerate, local limest
Mississipian through Cambrian		Leadville Ls, Ouray Ls, Elbert Fm, Chaffee Group, Fremont Ls, Harding Ss, Manitiou Dol, Sawatch Quartzite	limestone, dolomite, sandstone, chert
Precambrian		metamorphic and igneous rocks	granite, quartz monzonite, schist, and gneiss

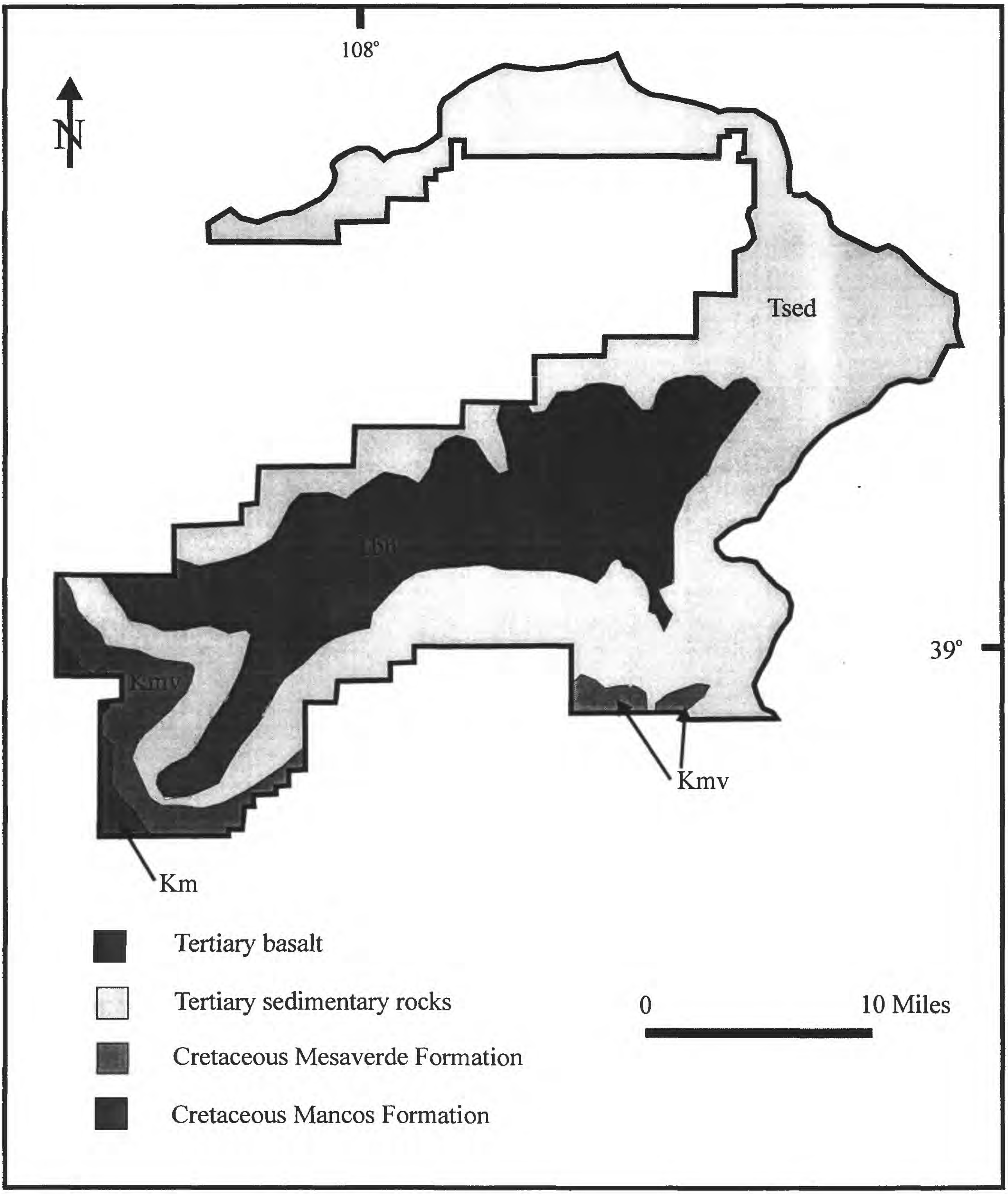

Figure 2. Generalized geologic map of the Grand Mesa National Forest (after Tweto, 1979).

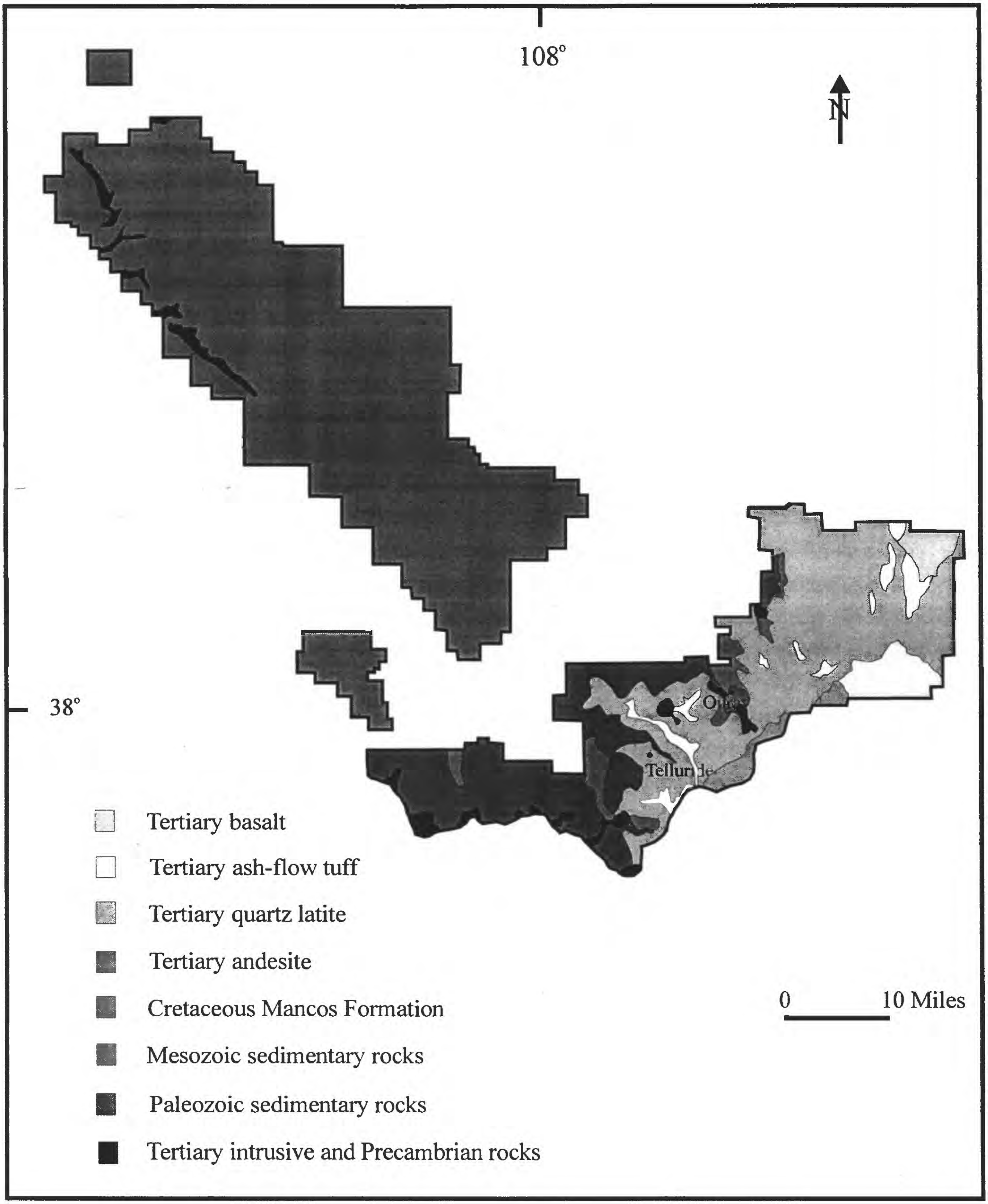

Figure 3. Generalized geology (after Tweto, 1979) of the Uncomphagre National Forest.

conglomerate, shale, and limestone, Mississippian Leadville Limestone and Devonian Ouray Limestone, and Elbert Formation of limestone, dolomite, arkosic sandstone, conglomerate, and shale and Tertiary and Proterozoic intrusive rocks and Proterozoic metamorphic rocks.

The major rock types within the Gunnison National Forest (fig. 4) consist of Pliocene to Miocene basalt flows and associated tuff, breccia, and conglomerate, Oligocene ash-flow tuff, Oligocene inter-ash flow quartz latitic lava and breccia, Oligocene andesitic lava and breccia, Oligocene Duchesne River Formation of sandstone and shale, Eocene and Paleocene Wasatch and Ohio Creek Formations of claystone, mudstone, sandstone, and conglomerate, Cretaceous Mesaverde Formation of sandstone and shale with coal beds, Cretaceous Mancos Shale of sandstone, shale, and conglomerate, Permian and Pennsylvanian Maroon Formation of arkosic sandstone, siltstone, conglomerate, and limestone, Pennsylvanian Minturn and Belden Formations of arkosic sandstone, shale, conglomerate, and limestone, Mississippian Leadville Limestone, Mississippian and Devonian Chaffee Group, Ordovician Fremont Limestone, Harding Sandstone and Manitou Dolomite, and Cambrian Sawatch Quartzite and Peerless Formation of limestone, dolomite, arkosic sandstone, shale, limestone, dolomite, ardosic sandstone, conglomerate and conglomerate and Tertiary and Proterozoic intrusive rocks and Proterozoic metamorphic rocks. The major rock types of the three National Forests are divided into ten dominant rock composition types (Table 2) and represent in some cases one rock formation such as the Mesavede Formation, or a group such as Cretaceous, Jurassic and Triassic sedimentary rocks of similar composition. The dominant rock types are: 1) Tertiary basalt flows and associated rocks; 2) Tertiary ash-flow tuff; 3) Tertiary quartz latitic lava and breccia; 4) Tertiary andesitic lavas and associated rocks; 5) Tertiary sedimentary rocks; 6) Cretaceous Mesavede Formation; 7) Cretaceous Mancos Shale; 8) Mesozoic sedimentary rocks consisting of Cretaceous, Jurassic, and Triassic sedimentary rocks of predominantly sandstone; 9) Paleozoic sedimentary rocks; and 10) Proterozoic and Tertiary plutonic rocks and Proterozoic gneiss, and schist. The ten dominant rock compositional types represent most of the rocks (>95%) within the three National Forests.

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. Both stream and spring sites were chosen to represent each of the ten major rock composition types within the three National Forests.

Samples of water were collected from stream and spring sites within the study area during July and August, 1998 and August, 1999. The waters were collected after runoff had occurred

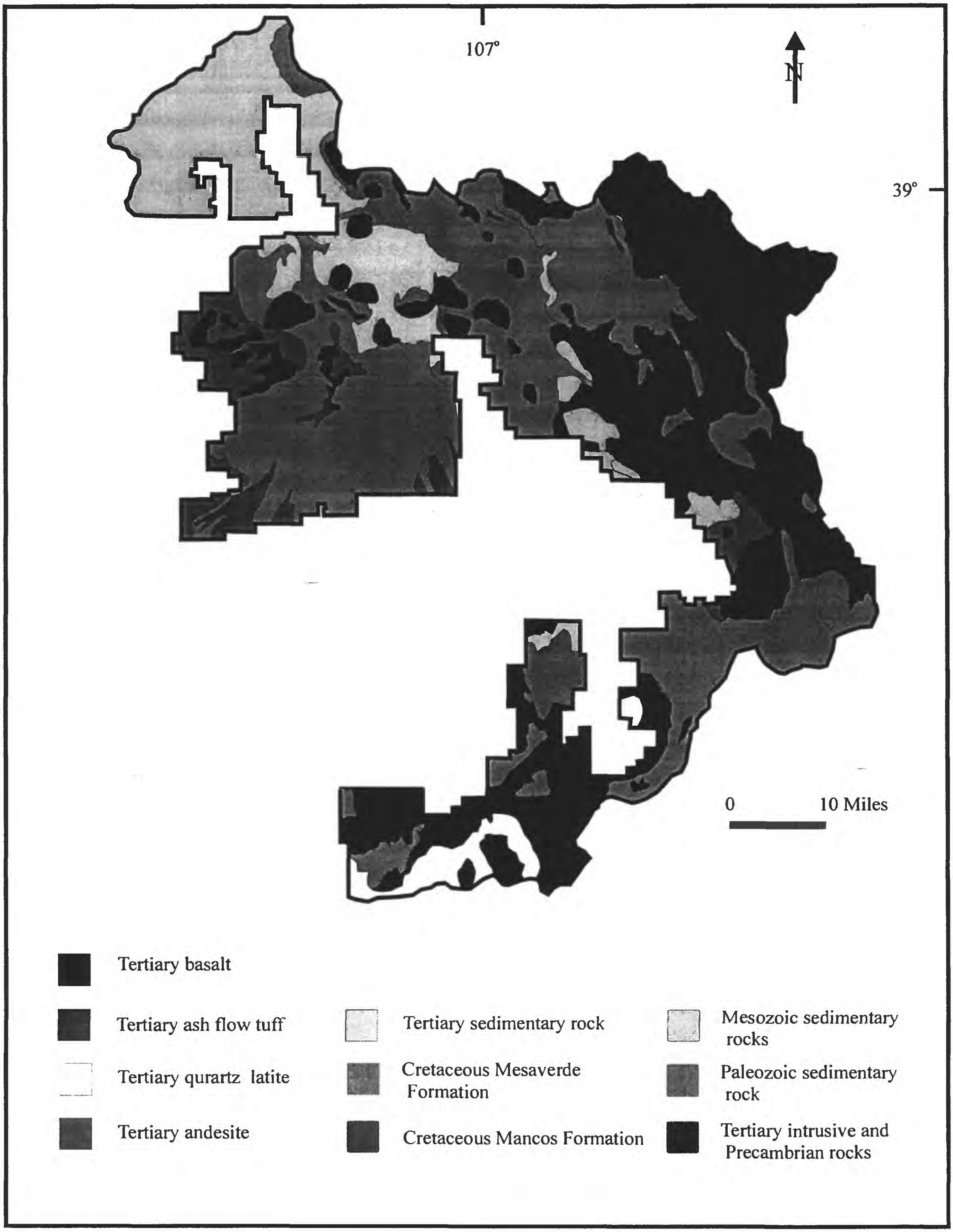

Figure 4. Generalized geology (after Tweto, 1979) of the Gunnison National Forest.

but prior to the streams reaching base flow or in some cases, drying up completely. Waters from areas underlain by each major rock composition type were usually collected within one or two days. Waters from areas of lower elevations were collected earlier in the season than the high alpine 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. An Orion model 250 pH meter was used with an Orion Ross Sure-Flow electrode. 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 - atomic emission spectromentry (ICP-AES) or inductively coupled plasma - mass spectromentry (ICP-MS). IC, ICP-AES, and alkalinity analyses were performed by Murdock Environmental Laboratory, University of Montana, Missoula, The ICP-MS analyses for samples collected in 1998 were determined by ACTLABS, Wheatridge, CO. The samples collected in1999 were determined by U.S.G.S. laboratories under the direction of Paul Lamothe. The ICP-AES analyses for samples collected in 1998 were determined by Murdock Environmental Laboratory. The samples collected in 1999 were determined by U.S.G.S. laboratories under the direction of Paul Briggs. Duplicate water samples, blank samples, and USGS Water Resource Division standard reference waters were analyzed with each data set. The chemical analyses are shown in appendix 1.

Results

Water samples were collected from small streams or springs of watersheds that were within or mainly within the three National Forests. The watersheds are mountainous headwaters and are not impacted by historic mining. Cattle is grazed in some of the watersheds which may have some impact on water quality. The samples were selected so that the geochemical baseline chemistry approximates the natural background geochemistry as closely as possible for each of the ten rock compositional types (Table 2) that are dominant in the three National Forests. The ranges and means of species and other parameters were determined for waters from areas

Table 2. The ten dominant rock compositon types in the Gunnison, Grand Mesa, and Uncompahgre Natoinal Forests

Period	Rock Composition Type	Setting
Tertiary	basalt flows and associated rocks	Grand Mesa
Tertiary	felsic ash flow tuff	San Juan volcanic field
Tertiary	quartz latitic lava and breccia	San Juan volcanic field
Tertiary	andesitic lava, breccia, and tuff	West Elk volcanic field
Tertiary	Tertiary sedimentary rocks of shale, oil shale, sandstone, marlstone, claystone, and lignite	Battlement and Grand Mesa
Cretaceous	Mesaverde Formation of sandstone, shale, coal, minor intrusive rock, and claystone	Piceance basin / Elk Mtns
Cretaceous	Mancos Formation of marine shale, sandstone, and calcareous sandstone	San Juan volcanic field/Paradox basin
Mesozoic	Mesozoic sedimentary rocks of sandstone, siltstone, shale, limestone, conglomerate, and mudstone	Uncompahgre uplift
Paleozoic	Paleozoic sedimentary rocks of sandstone, conglomerate, carbonate, quartzite, shale, mudstone, grit	West flank of Sawatch Range
Tertiary and Proterozoic	granite, quartz monzonite, felsic and hornblende gneiss	Sawatch Range, scattered throughout remaining area

underlain by each of the dominant rock composition types.

Tertiary basalt flows and associated rocks

Water samples were collected from four small streams draining areas underlain by Pliocene and Miocene basaltic lava, tuff, breccia, and conglomerate from the top of Grand Mesa in the Grand Mesa National Forest (fig. 5). The ranges and means of selected species in the waters are shown in Table 3. The complete chemical analyses of these sites and the remaining sites are shown in appendix 1. Grand Mesa rises more than a mile above the surrounding valleys. The basaltic rocks overlie the Tertiary Green River, Wasatch, and Ohio Creek Formations. Relief on the top of Grand Mesa is low. The area receives 30 to 45 inches of annual precipitation (Colorado Climate Center, 1984), and snow pack can range from 5 to 10 feet. Vegetation is mainly sub-alpine forest and grasslands. The sites contain dilute Ca^{2+}- HCO_3^- type waters with slightly alkaline pH values and moderate to low alkalinity values. Mean pH is 7.41 and mean conductivity is 63 µS/cm. The mean Cl concentration is 0.29 mg/l, indicating much of the water is snow melt with minimal time of contact with the rocks. Cl concentration is conservative and a good indicator of evaporation effects. All species are low in concentrations, except for Al. Mean Al concentration is 54 ug/l, probably because the initial low pH values of the melting snow is favorable for the mobility of Al. Generally, waters that are in contact with basaltic rocks are well buffered with moderate values of alkalinity. But the short time of contact of the melting snow with the basaltic rocks on Grand Mesa only allows the waters to pick up moderately low alkalinity values. Alkalinity ranges from 24 to 30 mg/l as HCO_3^- with a mean of 28 mg/l. This low mean value suggests that the top of Grand Mesa is moderately susceptible to introduced acidification. Introduced acidity from sources such as acid rain could consume the alkalinity in waters, causing the streams and lakes on the top of Grand Mesa to become acidic. Except for moderate amounts of Al, the waters from Grand Mesa are excellent in water quality.

Tertiary ash-flow tuff

Water samples were collected from three streams and two springs in the Los Pinos Creek and Pauline Creek watersheds in areas underlain by Oligocene rhyolitic ash-flow tuff in the Gunnison National Forest (fig. 6). The sources of the tuff are calderas in the San Juan Mountains to the south. The relief in the area is high and the dominant vegetation is subalpine forest. Annual precipitation ranges from 16 to 30 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 slightly acidic to slightly alkaline pH values and moderately low conductivities.

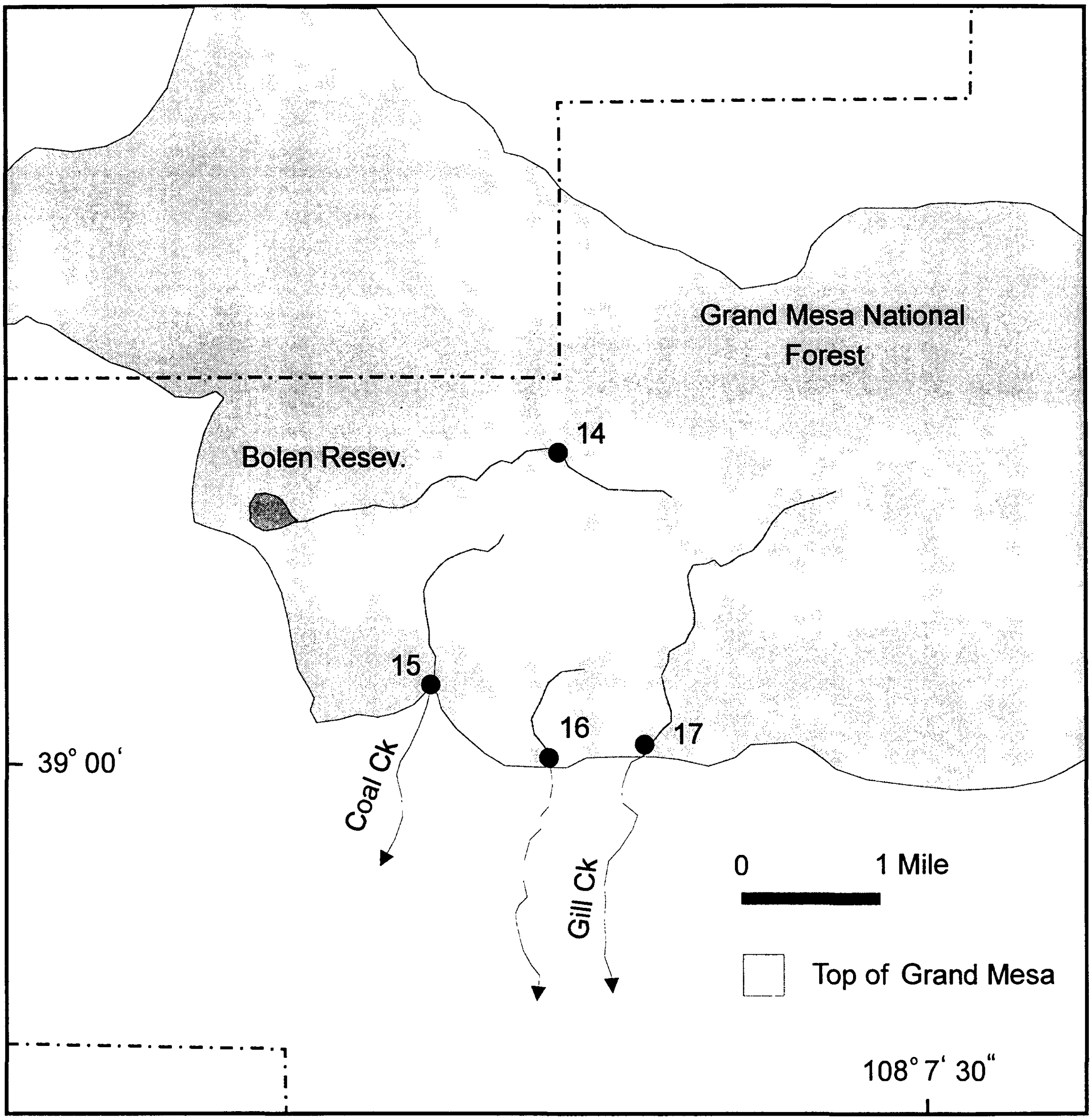

Figure 5. Site locations of stream waters from areas underlain by Tertiary basalt flows and associated rocks, Grand Mesa National Forest.

Table 3. Stream waters from watersheds underlain by Tertiary basalt flows, tuff, breccia, and conglomerates (n+4)

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	59	66	63
pH	7.09	7.67	7.41
Ca	4	6.1	5.4
Mg	1.8	2.3	2.1
Na	1.5	2	1.8
K	0.24	0.45	0.37
SiO_2	11	19	14
Alkalinity	24	30	28
SO_4	0.38	1.6	0.65
Cl	<0.25	0.6	0.29
F	<0.1	<0.1	<0.1
Al	38	107	54
Fe	44	151	91
Mn	4.2	27	15
Cu	<1	<1	<1
Zn	0.32	0.52	0.4
Pb	<0.1	1.4	0.15
Mo	<0.5	0.53	<0.5
Sb	<0.01	0.22	0.017
As	<0.03	0.67	0.048
Th	0.069	0.1	0.083
U	0.036	0.15	0.069
Li	<0.5	<0.5	<0.5
Ba	10	17	14
Sr	29	39	36
V	<0.5	0.57	<0.5
Sc	17	26	21
Rb	0.29	1.3	0.5
Y	0.31	0.53	0.41
Zr	0.28	1	0.43
La	0.17	0.31	0.25
Br	<3	<3	<3
I	<0.2	20	0.98

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, Conductivity in uS/cm, remaining elements in ug/l.
[2] All variables are geometric means except for pH which is arithmatic mean.

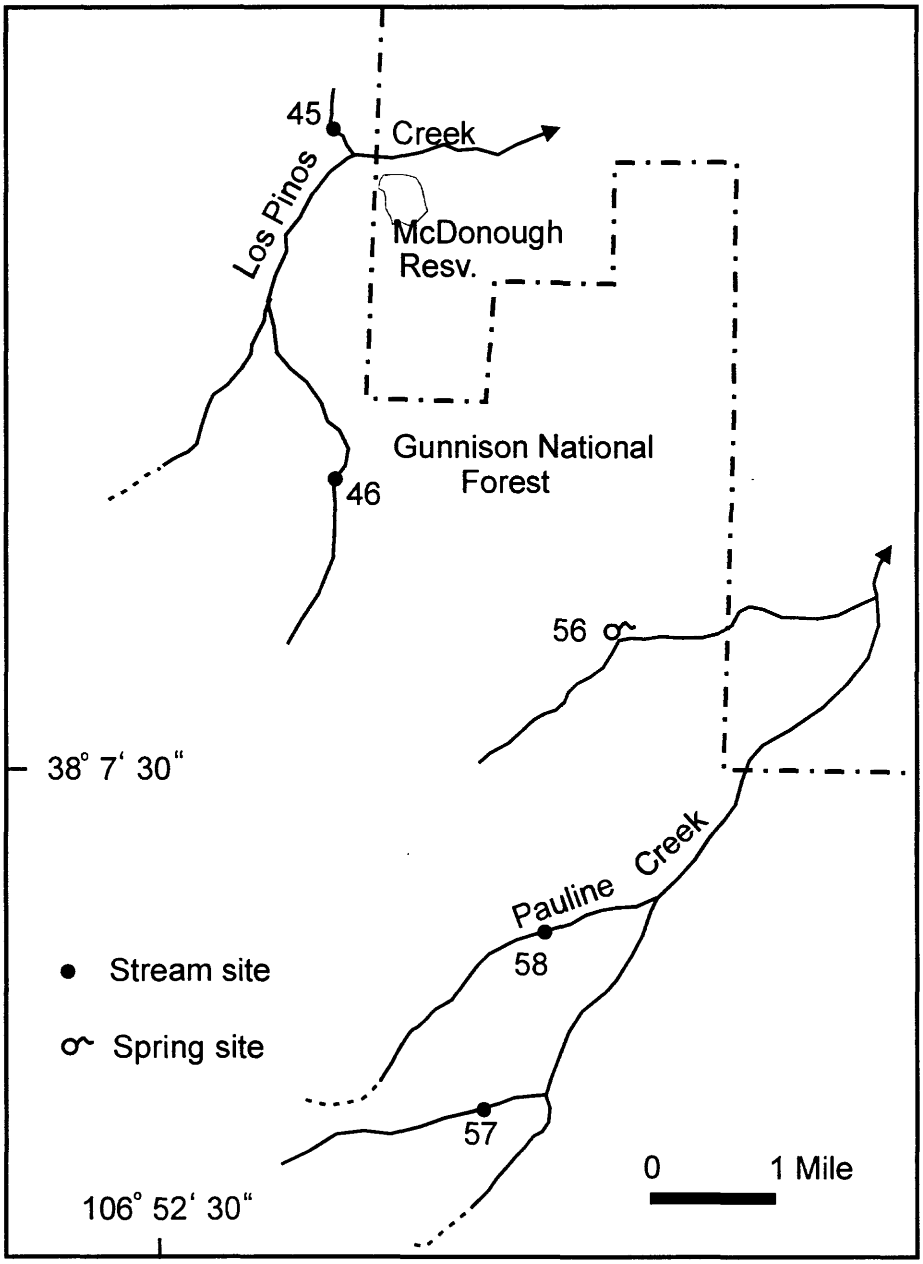

Figure 6. Site locations of stream and spring waters from areas underlain by Tertiary ash-flow tuff in the Los Pinios and Pauline Creek watersheds, Gunnison National Forest.

Table 4. Stream waters from watersheds underlain by Tertiary ash-flow tuff (n=5)

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	57	139	100
pH	6.89	8.02	7.43
Ca	5.3	16.5	11
Mg	0.83	2.8	1.7
Na	3.1	7.9	4.4
K	0.87	2.3	1.3
SiO2	19	41	29
Alkalinity	32	70	46
SO4	1.4	6	2.7
Cl	0.37	1.9	0.88
F	<0.1	0.14	0.1
Al	6.7	34	16
Fe	9.5	640	65
Mn	<0.3	32	2.9
Cu	<1	<1	<1
Zn	<0.2	0.32	0.24
Pb	<0.1	1.1	0.12
Mo	<0.5	0.6	<0.5
Sb	<0.01	0.13	0.021
As	0.79	2.2	1.2
Th	0.07	0.57	0.19
U	0.012	0.2	0.058
Li	0.86	2.8	1.5
Ba	10	32	18
Sr	47	109	79
V	<0.5	3.4	1.2
Sc	22	51	35
Rb	0.3	3.1	1.2
Y	0.047	0.18	0.1
Zr	0.12	19	0.51
La	<0.005	0.17	0.024
Br	<3	33	3.5
I	<0.2	7.8	2.2

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

Mean pH is 7.43 and mean conductivity is 100 μS/cm. Mean Zn is very low at 0.24 μg/l and Cu at <0.1 μg/l. SiO_2 concentrations ranged from 19 to 41 mg/l with a mean of 29 μg/l. These higher concentrations of SiO_2 are probably because of the felsic rock composition and the fine-grain size of the minerals which compose the rocks are more susceptible to weathering. Alkalinity values ranged from 32 to 70 mg/l as HCO_3^- with a mean of 46 mg/l. This moderately low value is mainly because the felsic composition rocks do not weather as rapidly as more mafic rocks. Mean Cl content is 0.88 mg/l, which is low and reflects the short residence time of the melting snow and rain in contact with the rocks and lack of significant evaporation. Two stream waters were high in Fe concentrations with 255 and 640 μg/l respectively. Both sites were contaminated by cattle wastes and were slightly yellow brown in color. The wastes probably caused more reducing conditions which favors the mobility of Fe. Another possibility for the Fe mobility may be due to Fe complexing with organic matter. Except for the Fe concentrations in the two samples, the waters in the watersheds underlain by the Tertiary ash-flow tuff are of good chemical quality. The felsic rock type and the short contact time of the water and rock favor moderately low alkalinity. The moderately low alkalinity values make the area moderately susceptible to introduced acidification. Moderate amounts of acidification from mining or atmospheric precipitation could consume the alkalinity and cause the stream waters to become acidic.

Tertiary quartz latitic lava and breccia

Samples of water were collected from four streams in the Mineral Creek drainage in the northern part of the San Juan volcanic field in the La Garita Wilderness, Gunnison National Forest (fig. 7). The area is underlain by Oligocene inter-ash flow quartz latitic lava and breccia.(Tweto and others, 1976). Relief is high and the dominant vegetation is subalpine forest. Annual precipitation ranges from 16 to 25 inches (Colorado Climate Center, 1984). The ranges and means of selected species in the waters are shown in Table 5. The sites contain three Ca^{2+}-HCO_3^- and one Na^+- HCO_3^- type waters with slightly alkaline pH values and moderately low conductivities. Mean pH is 7.48 and mean conductivity is 124 μS/cm. Trace metal concentrations are low. Mean Zn, Cu, Mo, and As are 0.5, 0.56 , 0.54, and <3 μg/l, respectively. The range of SiO_2 concentrations is 20 to 56 mg/l with a mean of 31 mg/l. The higher values are probably due to the felsic composition of the rocks and the fine-grain size of the rock minerals with high surface areas, which favor chemical dissolution of the silicates. The mean concentrations of Al and Fe are moderately high with means of 60 and and 55 μg/l respectively. The concentration of Mn is low with a mean of 2.7 μg/l. The mean Cl concentration is 0.56 mg/l, which is low and reflects the short residence time of the water from melting snow and rain

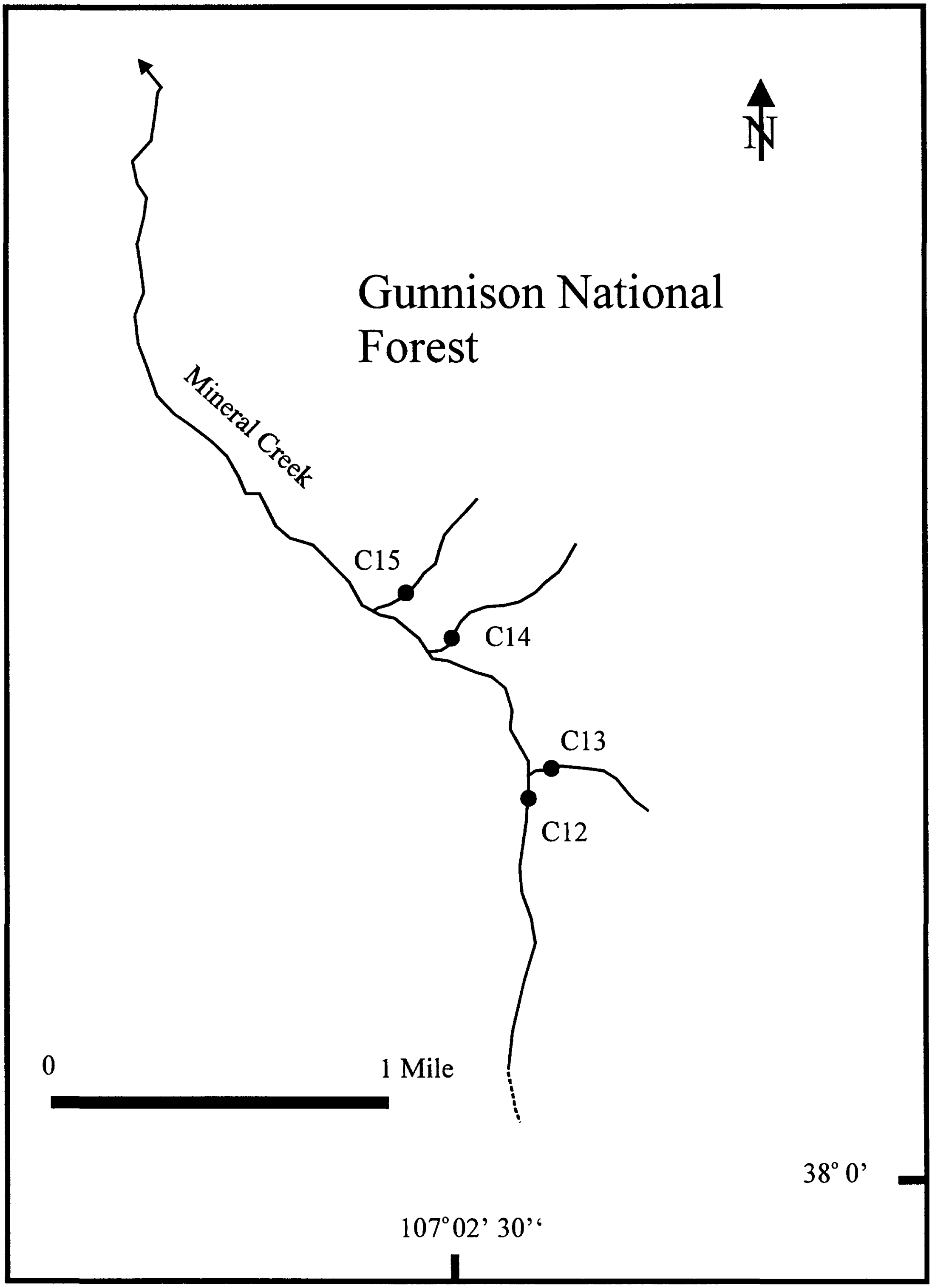

Figure 7 . Site locations of stream waters collected from areas underlain by intra-ash-flow quartz latite lavas, in the Mineral Creek watershed, Gunnison National Forest.

Table 5. Four stream waters from watersheds underlain by Oligocene quartz latitic lava and breccia

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	108	140	124
pH	7.35	7.75	7.48
Ca	8.7	16	12.6
Mg	0.78	2.9	1.8
Na	3.7	13	6.9
K	0.69	2.2	1.1
SiO_2	20	56	30.8
Alkalinity	29	44	36
SO_4	10	28	16.6
Cl	<0.25	1.5	0.56
F	<0.1	<0.1	<0.1
Al	7.9	356	55
Fe	33	159	60
Mn	1	21	2.7
Cu	<0.5	0.8	0.56
Zn	<0.5	1	0.5
Pb	<0.05	<0.05	<0.05
Mo	0.3	1	0.54
Sb	<0.1	0.2	<0.1
As	<3	<3	<3
Th	<0.005	0.15	0.03
U	0.08	0.32	0.14
Li	1.7	10	3.6
Ba	2.6	13	4.6
Sr	58	171	115
V	0.8	1.6	1.1
Sc	1.9	5.3	2.9
Rb	0.9	3	1.4
Y	0.1	1.5	0.32
Zr	0.08	1.4	0.32
La	0.05	0.5	0.13

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

in contact with the rocks and the lack of significant evaporation. The alkalinity as HCO_3^- ranged from 29 to 44 mg/l with a mean of 36 mg/l, which indicates weakly acid- neutralizing capacity. The felsic rock type and the short contact time of the water and rock favor moderately low alkalinity values. Because of the moderately low alkalinity values, the areas underlain by quartz latitic rocks are moderately susceptible to introduced acidification. Moderate amounts of acidification could consume the alkalinity and cause the stream waters to become acidic. The chemical quality of the waters from watersheds underlain by Tertiary quartz latitic rocks is good.

Tertiary andesitic rocks

Water samples were collected from eight streams in the Soap Creek area of the West Elk Mountains, Gunnison National Forest (fig. 8). The area is underlain by Oligocene andesitic lava flow, tuff, breccia, and conglomerate. The andesitic rocks originated from the nearby West Elk volcanic centers. Relief is high and the dominant vegetation is subalpine forest. 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 6. The area contains Ca^{2+}- HCO_3^- type waters with alkaline pH values and moderate conductivities. Mean pH is 7.99 and mean conductivity is 158 μS/cm. Trace element concentrations are low to very low. Mean Zn, Cu, Mo, and As are 0.22 μg/l, <1 μg/l, <0.5 μg/l, and 0.7 μg/l, respectively. The range of SiO_2 concentrations is 22 to 48 mg/l with a mean of 35 mg/l. The higher values are probably due to the fine-grain size of the rock minerals with high surface area, which favors dissolution of silicates. The mean concentrations of Al, Fe, and Mn are moderately low with means of 13, 16, and 0.48 μg/l respectively. The mean Cl concentration is 0.7 mg/l, which is low and reflects the short residence time of the waters from melting snow and rain in contact with the rocks and the lack of significant evaporation. The alkalinity as HCO_3^- ranged from 32 to 102 mg/l with a mean of 72 mg/l, which indicates moderate acid- neutralizing capacity for introduced acidification. Even though the residence time of water and rock is short, the fine-grain minerals and the intermediate composition of the rocks ensure that the rate of chemical weathering is rapid. Therefore the waters of this area, underlain by Tertiary andesitic rocks, have moderate acid-neutralizing capacity for introduced acidification. The chemical quality of the waters from watersheds underlain by Tertiary andesitic rocks is good.

Tertiary sedimentary rocks

Samples of water were collected from seven streams draining headwater watersheds underlain by Eocene Green River, Wasatch, and Ohio Creek Formations in the Grand Mesa

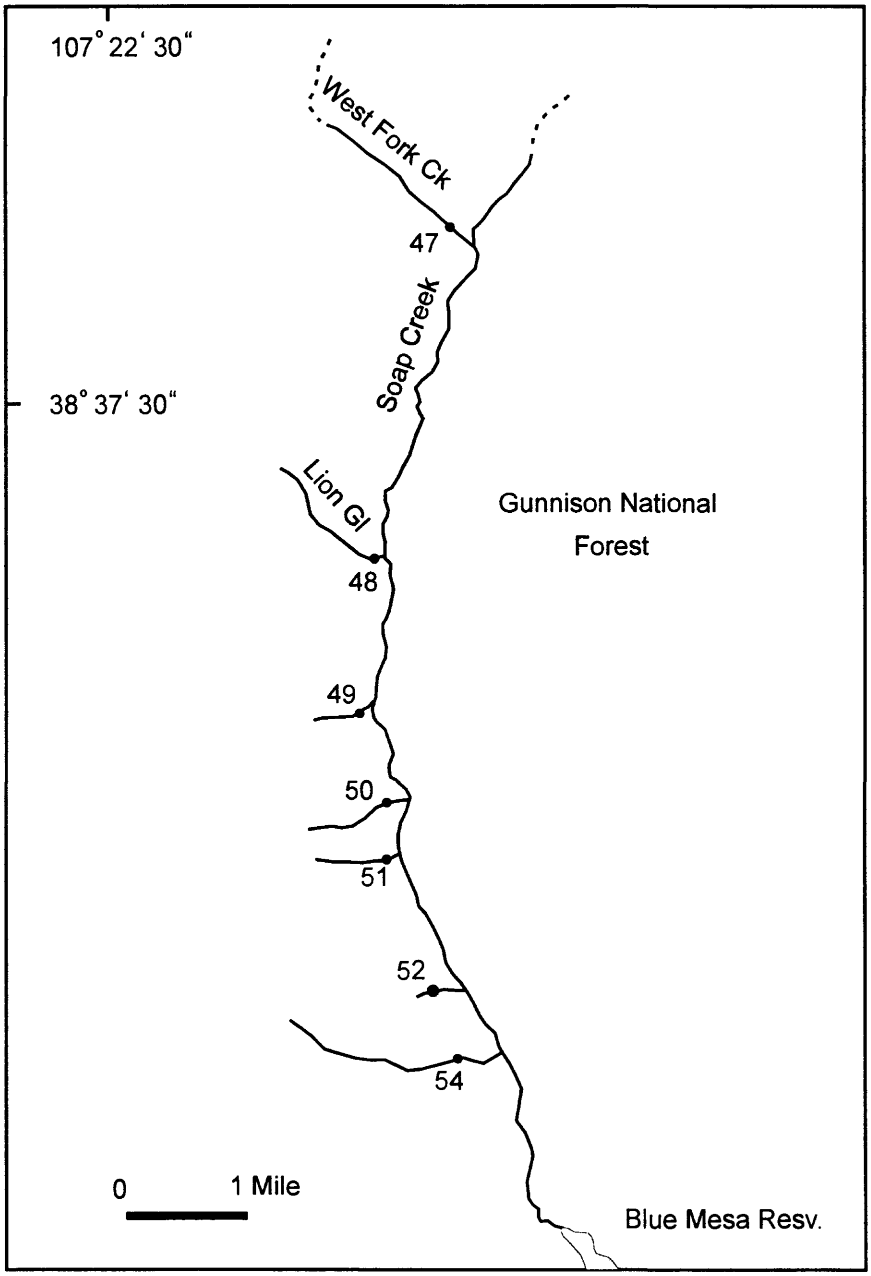

Figure 8. Site locations of stream waters from areas underlain by Tertiary andesites in the Soap Creek watershed, Gunnison National Forest.

Table 6. Eight stream waters from watersheds underlain by Oligocene andesitic lava and breccia

Measurment[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	104	242	158
pH	7.49	8.53	7.99
Ca	10	22	16
Mg	1.6	7.7	3
Na	4.8	15	7.7
K	0.81	2.4	1.7
SiO2	22	48	35
Alkalinity	32	102	72
SO4	0.76	23	3.5
Cl	0.34	1	0.7
F	<0.1	0.14	<0.1
Al	8.9	21	13
Fe	8.6	31	16
Mn	<0.3	4	0.48
Cu	<1	<1	<1
Zn	<0.2	0.38	0.22
Pb	<0.1	<0.1	<0.1
Mo	<0.5	0.59	<0.5
Sb	<0.01	0.074	0.012
As	0.4	1.3	0.7
Th	0.12	0.37	0.2
U	<0.001	0.28	0.092
Li	0.79	2.9	1.3
Ba	1.5	9.2	5
Sr	60	149	95
V	0.8	2.9	2.2
Sc	26	54	41
Rb	1.4	3.7	2.4
Y	0.05	0.11	0.071
Zr	0.15	0.45	0.27
La	<0.005	<0.005	<0.005
Br	<3	<3	<3
I	<0.2	2.2	0.21

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

National Forest (fig. 9). The Wasatch and Ohio Creek Formations were formed from detritus shed from the rising Rocky Mountains onto vast river flood plains and deltas flanking an immense lake (Bradley, 1964 and Roehler, 1974). The Green River Formation formed within the immense lake with large accumulations of plant and animal detritus, which resulted in oil shale (Bradley, 1964 and Roehler, 1974). Many of the sites were selected because of the presence of outcrops of the Parachute Member of the Green River Formation, which contains oil shale, in the sampled watersheds.

The watersheds are located along the flanks of Battlement Mesa and Grand Mesa. Relief ranges from moderate to high. The area receives from 20 to 35 inches of annual precipitation (Colorado Climate Center, 1984). The higher elevations receive the higher precipitation. Vegetation is mainly oak scrublands and subalpine forest in the higher areas. Some of the watersheds are physically impacted by cattle grazing with the increase in sediments in streams and the deterioration of wetlands from the hooves of cattle and accumulation of cattle wastes.

The ranges and means of selected species in waters are shown in Table 7. The sites all contain Ca^{2+}- HCO_3^- type waters with alkaline pH values and moderately high conductivity values. The mean pH is 8.50 and the mean conductivity is 365 µS/cm. Therefore the waters are moderately high in mean conductivity values for headwater watersheds. The waters are well buffered with mean alkalinity of 191 mg/l as HCO_3^-. Cl concentrations are conservative and a good indicator for evaporation effects. The mean Cl concentration is 1.4 mg/l. Background Cl for this area is probably less than 0.5 mg/l in the absence of input of Cl from weathering of rocks. There may be some input of Cl from these rocks. Halite is known to be present in oil shale in the subsurface (Tuttle, 1992). Some of the waters may have undergone evaporation and concentration in the soil and weathered rock zones and then input as groundwater along the stream channels. Mean concentration of SiO_2 is 17.5 mg/l, which is slightly above the average background concentration for fresh water (Table 8). Cu, Zn, and other trace metals present as cations are very low in concentrations (< 1 µg/l), even though the oil shale in the Green River Formation contains anomalous concentrations of trace metals (Harrison and others, 1992). The high pH values ensure that hydrolysis reactions keep the trace metal cations low in concentrations. This is not true with some of the trace species present as anions, which are slightly elevated in concentrations. Mean concentrations of Mo, As, and U are 1.9, 1.9, and 1.4 µg/l, respectively. These values are high compared to average fresh water (Table 8). In addition, the elements I, Br, Li, and Sr are elevated in concentration compared to fresh water (Table 8). Even though these elements are elevated, particularly for head water watersheds, no element poses a problem for water quality.

Five of the streams that were sampled drain watersheds with outcrops of the Parachute member of the Green River Formation (appendix 1), which contains oil shale. Pyrite is present

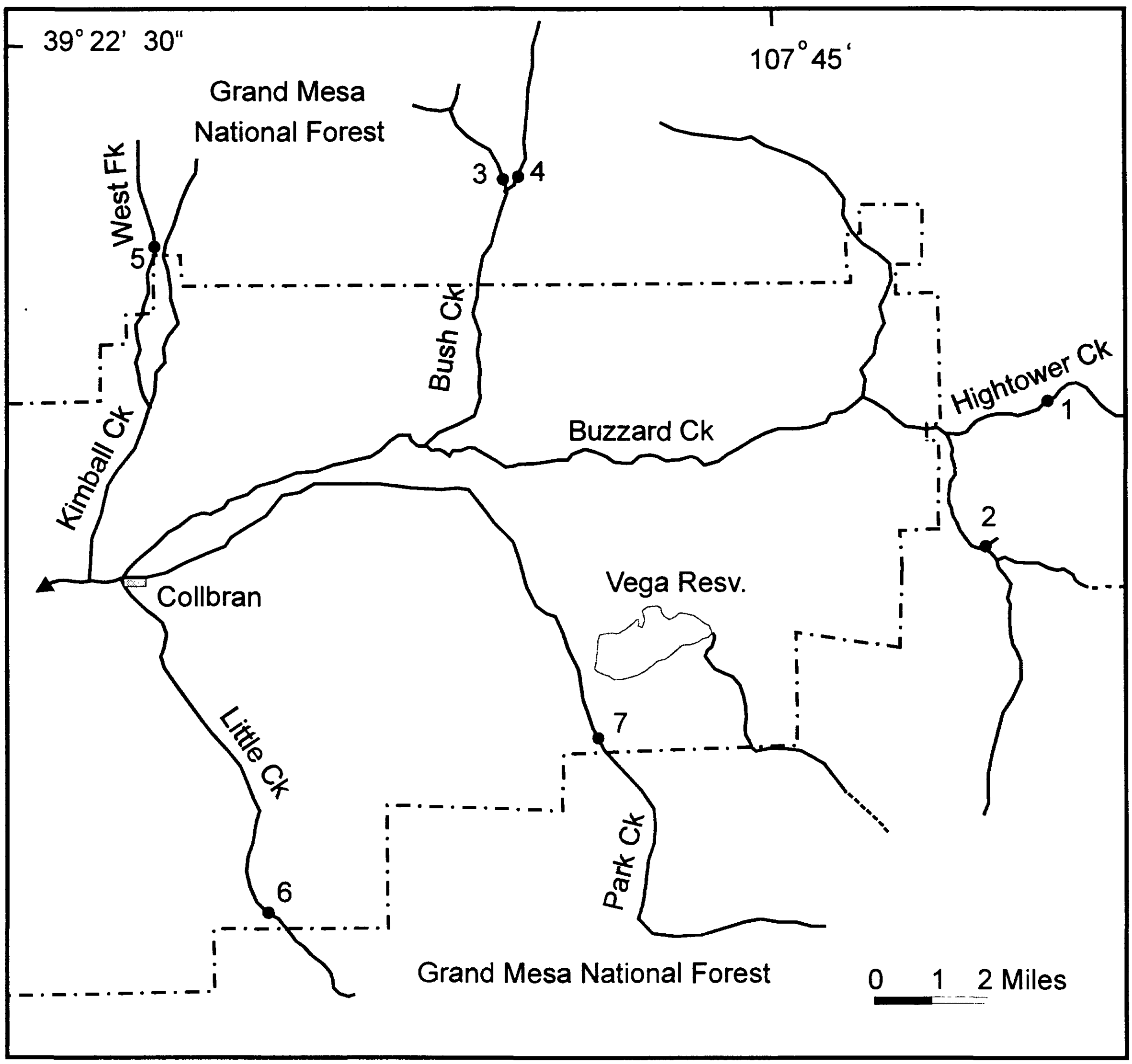

Figure 9. Site locations of steam waters from areas underlain by Eocene Green River, Wasatch, and Ohio Creek Formations in the Buzzard Creek watershed, Grand Mesa National Forest.

Table 7. Waters from areas underlain by Tertiary Sediments of marlstone, oil shale, siltstone, claystone, mudstone, sandstone, and conglomerate (n=7).

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	195	652	365
pH	8.16	8.69	8.50
Ca	18	62	39
Mg	6.6	37	12
Na	5.2	45	15
K	0.65	3.8	1.4
SiO2	6.5	27	18
Alkalinity	92	352	191
SO4	3.4	25	8.1
Cl	0.63	8.3	1.4
F	<0.1	0.51	0.16
Al	<3	24	12
Fe	<5	36	13
Mn	<0.3	171	4.7
Cu	<1	1.7	<1
Zn	<0.2	0.53	0.22
Pb	<0.1	2.9	0.18
Mo	0.53	7.5	1.9
Sb	<0.01	0.29	0.12
As	0.62	5.8	1.9
Th	0.18	1.5	0.36
U	0.39	8.8	1.4
Li	1.3	25	7.2
Ba	32	208	62
Sr	114	718	311
V	1.3	5.5	2.8
Sc	11	36	25
Rb	0.4	0.84	0.6
Y	0.05	0.17	0.083
Zr	0.14	1.3	0.42
La	<0.005	0.072	0.017
Br	<3	182	6.6
I	<0.2	36	1.5

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

Table 8. Background of trace metals in freshwater and chemical analyses of mean river water.

Background of trace metals in freshwater	
Element	Data from Forstner and Wittmann (1979)
Al	<30
Cr	0.5
Fe	<30
Mn	<5
Ni	0.3
Zn	10
Ag	0.3
Al	<30
As	2
Au	0.01
B	10
Ba	10
Be	0.01
Cd	0.07
Co	0.05
Cr	0.5
Cu	1.8
Fe	<30
Li	1
Mn	<5
Mo	1
Ni	0.3
Pb	0.2
Sb	0.1
Se	0.1
Sr	50
Sn	0.03
Ti	<1
U	0.5
V	0.9
Zn	10

Chemical analyses of mean river water	
Element in mg/l	Data from Livingstone (1963)
Ca	15
Mg	4.1
Na	6.3
K	2.3
SiO_2	13.1
SO_4	11.2
HCO_3	58.4
Cl	7.8

in the oil shale and will oxidize and release sulfate, trace metals contained in the pyrite, and acidity to the waters. The well buffered waters with high alkalinity values react and consume acidity release during the oxidation of pyrite, and the high pH values hydrolyze any trace metals carried as cations and reduce their mobility. Sulfate value, up to 25 mg/l, indicate that pyrite is weathering and sulfate is being released. There are some elevated As values, up to 5.8 μg/l (appendix 1), probably from the weathering of pyrite, but overall there is no significant impact to the water quality of these headwater streams. The high alkalinity of the waters is probably due to the presence of marlstone. The marlstones are fine-grained and the calcite reacts rapidly, releasing carbonate species, mostly bicarbonate, to the waters. Because of the high alkalinity values, the watersheds underlain by these rock are not susceptible to introduced acidification from processes such as acid rain or acid-mine drainage. The waters evolving from the watersheds underlain by the Green River, Wasatch, and Ohio Creek Formations are moderately high in dissolved solids for headwater streams, but pose no human health risk in terms of chemical water quality.

Cretaceous Mesavede Formation

Water samples were collected from seven streams and one spring in the Coal Creek area along the northern flank of the West Elk Mountains in the Gunnison National Forest (fig.10). The ranges and means of selected species in water are shown in Table 9. The area containing the sample sites is underlain by Late Cretaceous Mesaverde Formation rocks. Minor amounts of Oligocene intermediate-composition intrusive rocks are also present in some watersheds. The Mesaverde Formation consists of mostly sandstone with some shale and coal beds. The rocks were deposited in sand beach, river delta, and swamp environments. The economically important low-sulfur bituminous coal beds resulted from accumulation of organic material in marshes and lagoons that formed behind sand-barrier islands (Benedict, 1991). The relief of the area is high and annual precipitation ranges from 20 to 35 inches (Colorado Climate Center, 1984). Dominant vegetation is subalpine forest. The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values and moderate conductivity values. Values for pH ranged from 8.00 to 8.57 with a mean of 8.31. Conductivity values ranged from 76 to 268 μS/cm with a mean of 126 μS/cm. The mean Cl content is 0.49 mg/l, which suggests that no significant evaporation and no long term contact of the water with the rocks has taken place. A significant portion of the stream water is probably snow melt. The range in concentrations of SiO_2 is 11 to 15 mg/l with a mean of 13 mg/l, which is about average for fresh water (Table 8). The coarser grain size and the well crystallized nature of the silica minerals are probably the reason that the waters from areas underlain by sandstones contain less SiO_2 than the finer grained size minerals of the ash-flow tuff

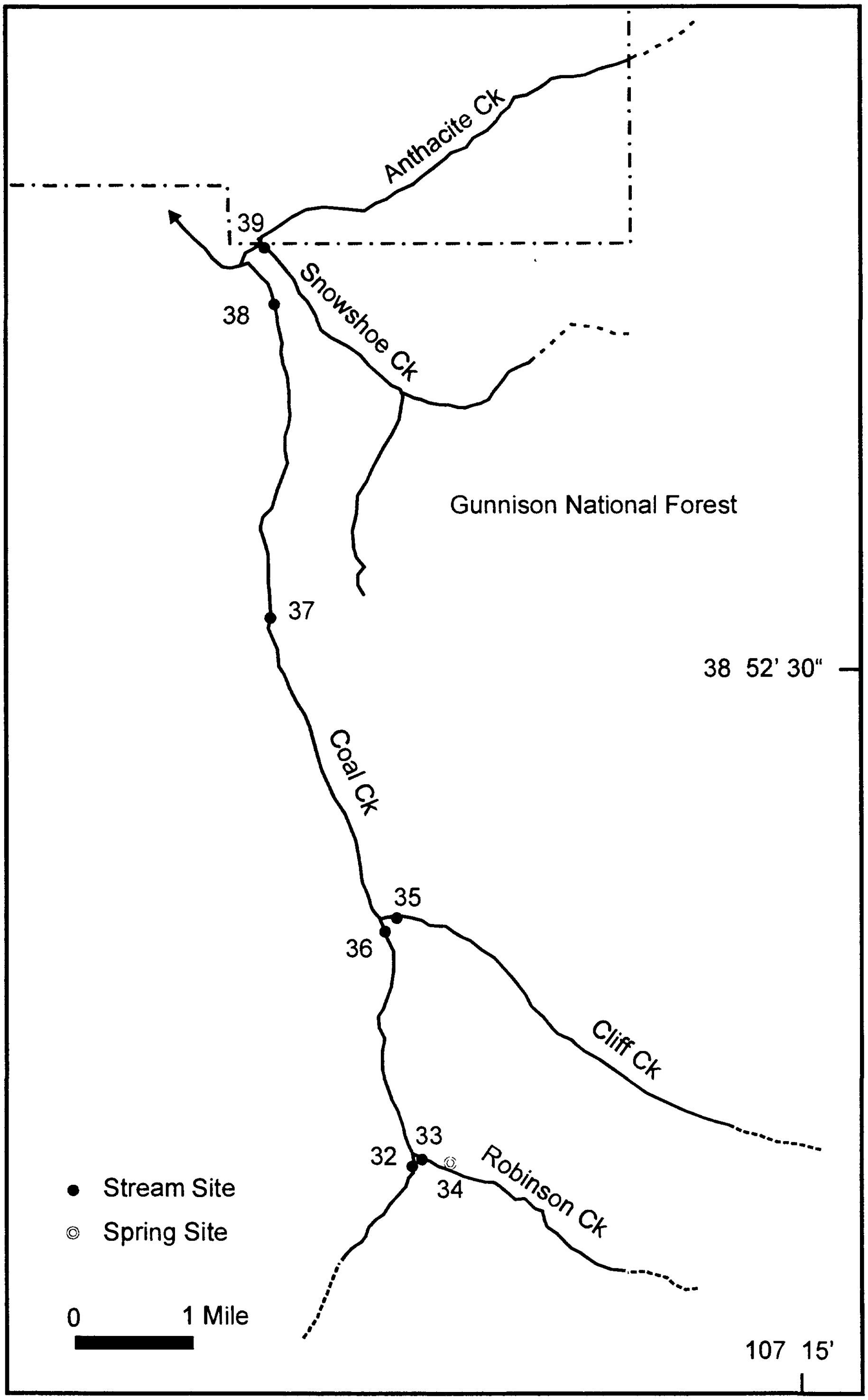

Figure 10. Site locations of stream and spring waters from areas underlain by Cretaceous Mesaverde Formations in the Coal Creek and Snowshoe Creek watersheds, Gunnison Naional Forest.

Table 9. Eight waters from areas underlain by the Mesaverde Formation of sandstone, shale, and major coal beds

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	76	268	126
pH	8	8.57	8.31
Ca	7.7	31	13
Mg	1.3	8.3	3
Na	3.8	13.4	5.4
K	0.32	0.81	0.49
SiO2	11	15	13
Alkalinity	34	122	54
SO4	1.5	19	5.3
Cl	0.25	1	0.49
F	<0.1	0.75	0.11
Al	9	27	12
Fe	<5	30	14
Mn	1.4	7	2
Cu	<1	<1	<1
Zn	<0.2	0.36	0.24
Pb	<0.1	<0.1	<0.1
Mo	<0.5	0.63	<0.5
Sb	<0.01	<0.01	<0.01
As	<0.03	2.4	0.08
Th	<0.002	0.023	0.003
U	0.077	0.51	0.13
Li	0.72	4.7	1.4
Ba	11	49	18
Sr	52	364	189
V	<0.5	0.74	<0.5
Sc	16	21	18
Rb	0.14	0.45	0.32
Y	<0.03	0.12	0.042
Zr	<0.05	0.62	0.15
La	<0.005	0.089	<0.005
Br	<3	<3	<3
I	<0.2	<0.2	<0.2

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

and andesitic rocks. The concentrations of trace elements Zn, Cu, Mo, and As are very low, with means of 0.24, <1, and <0.5, and <0.08 μg/l, respectively. Concentrations of Al, Fe, and Mn are also low in with means of 12, 14, and 2 μg/l, respectively. Alkalinity values range from 34 to 122 mg/l as HCO_3^- with a mean of 54 mg/l. This wide range in alkalinity values may be due to the presence of pyrite associated with the coal beds. Weathering of pyrite releases acid to the waters, which consumes alkalinity. The moderately low mean alkalinity suggests low to moderated acid-neutralizing capacity of the watershed to introduced acidification. Overall the water quality of the area is good to excellent.

Cretaceous Mancos Shale

Water samples were collected from two areas underlain by the Mancos Shale. Six streams were sampled in the southwestern part of the Uncompahgre National Forest in the area of McCulloch, Beaver, and Goat Creek (fig. 11). Two springs were sampled along the northwestern flank of the West Elk Mountains in the area of Bell Creek in the Gunnison National Forest (fig. 12). The ranges and means of selected species in water are shown on Table 10. The Cretaceous Mancos Shale consists of silty and sandy shale and thin bedded sandstone with calcareous zones deposited in a marine setting. The two areas are of high relief and annual precipitation ranges from 16 to 40 inches (Colorado Climate Center, 1984). Dominant vegetation in both areas is subalpine forest, but in lower areas outside the National Forest, badland topography with sparse scrub vegetation is present. The sites all contain Ca^{2+}- HCO_3^- type waters with alkaline pH values and moderately high conductivity values. Values of pH range from 7.46 to 8.58 with a mean of 8.20. Conductivity values range from 107 to 401 μS/cm with a mean of 258 μS/cm. The mean Cl content is 0.6 mg/l, which suggests that evaporation and time of contact of the waters with rocks and soils is not significant. It is possible that some of the Cl may come from the weathering of the rocks, but the low concentration of Cl suggests that this process is insignificant. Note that these sites are in higher elevation areas and do not necessarily reflect the processes that are going on in the lower elevation, less-vegetated areas underlain by the Mancos Shale outside the National Forests. Mean concentrations of SiO_2 is 13 mg/l which is about average for fresh water (Table 8). Concentrations of trace elements are mainly low with mean Zn, Cu, Mo, and As values of 0.21, <1, 0.71, and 0.12 μg/l, respectively. One reason for high concentrations of Se in waters in the lower valleys is thought to be due to high Se concentrations in the Mancos Shale. In these headwater watersheds underlain by the Mancos Shale, Se concentrations in waters are all <0.2 μg/l. The high Se concentrations in the lower valleys are probably due to evaporation effects from natural processes and irrigation. Se, similar to Cl, will concentrate with evaporation. The concentrations of Al, Fe, and Mn are low at 10, 15, and 2.2

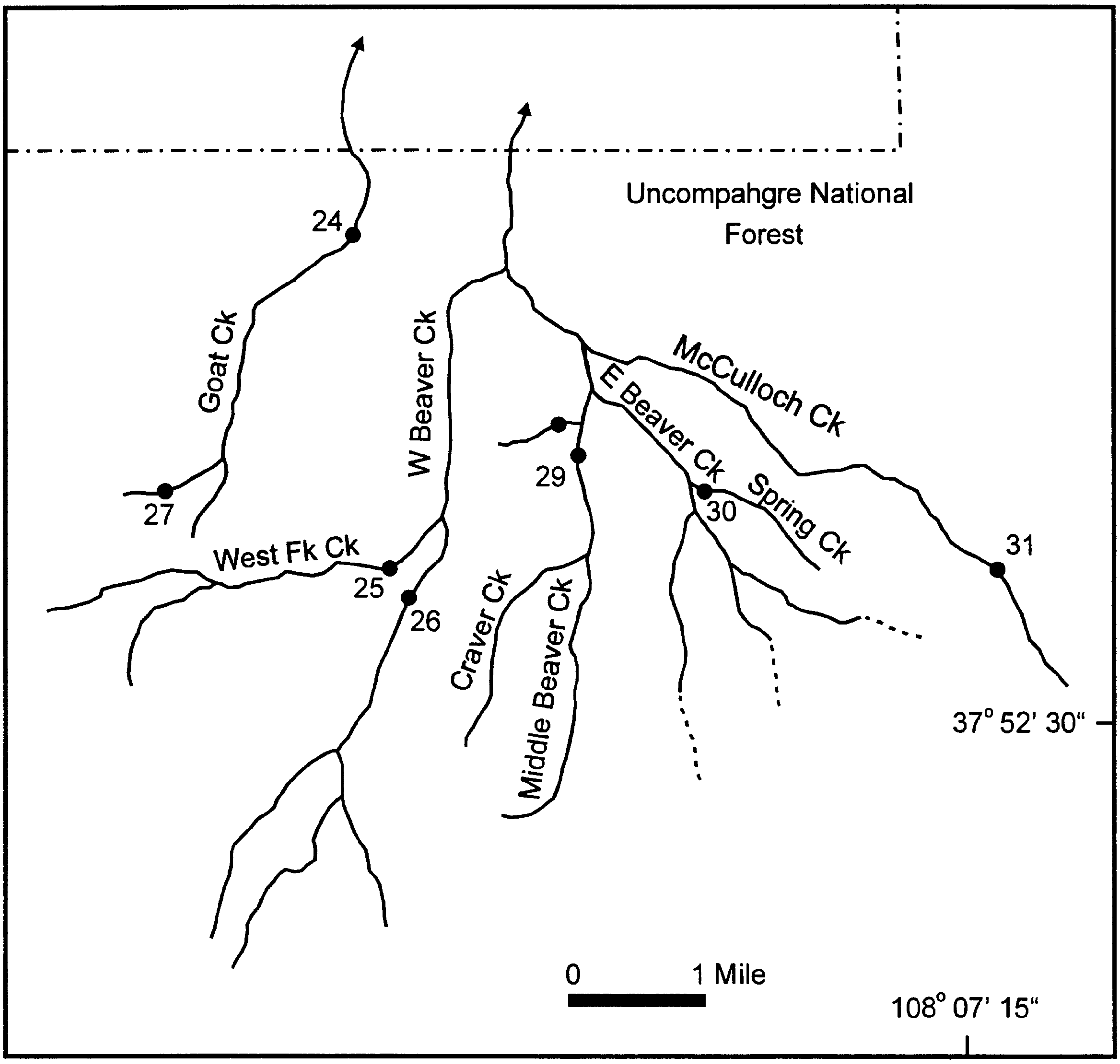

Figure 11. Site locations of stream waters from areas underlain by Cretaceous Mancos Formation in the Beaver and Goat Creek watersheds, Uncompahgre National Forest.

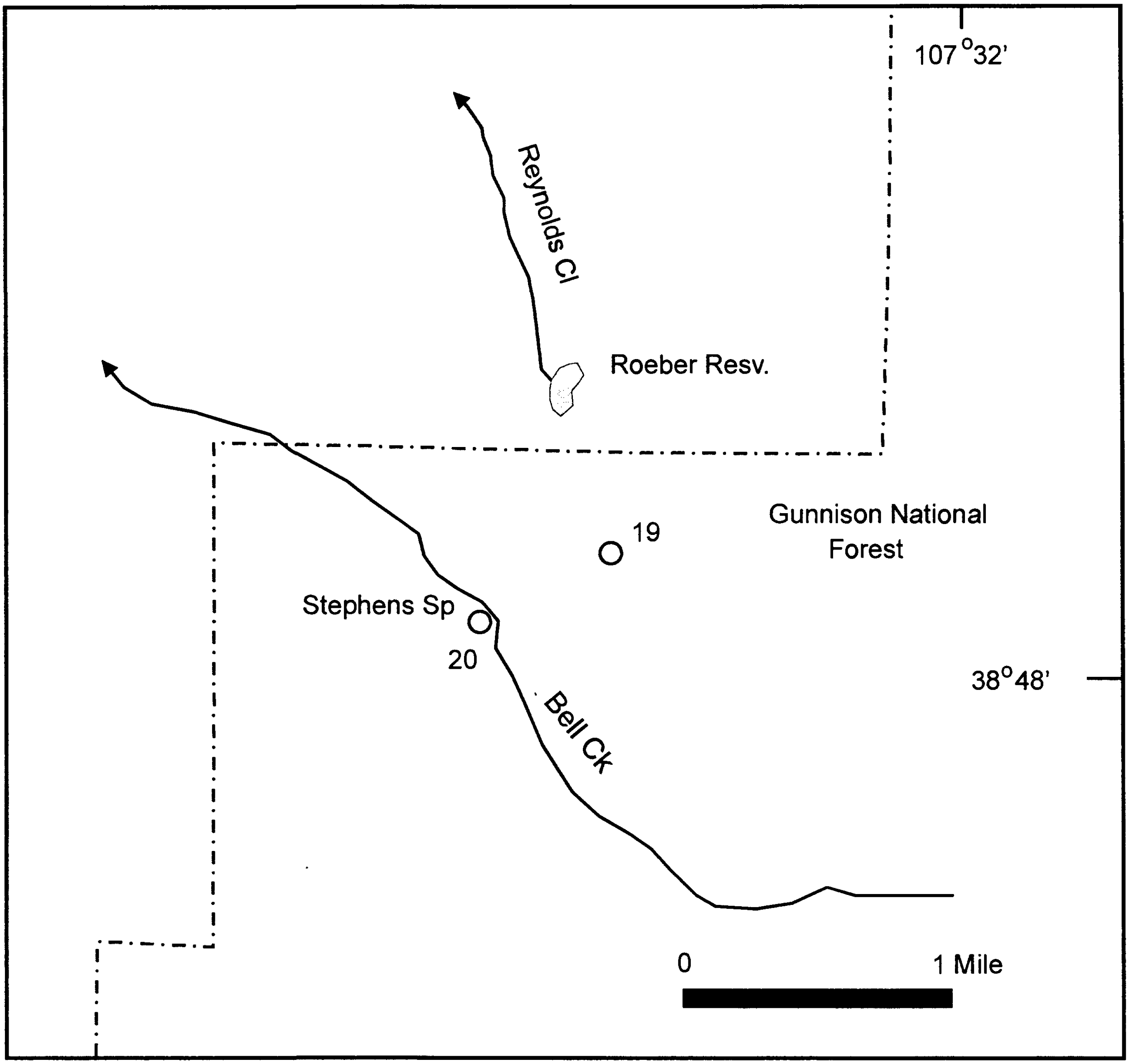

Figure 12. Site locations of spring waters from areas underlain by Cretaceous Mancos Formation in the Bell Creek area, Gunnison Naional Forest.

Table 10. Ten waters from areas underlain by Mancos Shale of shale, calcarous shale and sandstone

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	107	401	258
pH	7.46	8.58	8.20
Ca	12	50	32
Mg	2.3	13	7.5
Na	2.5	13	4.7
K	0.15	1	0.36
SiO2	8.6	27	13
Alkalinity	30	180	101
SO4	6.1	37	18
Cl	0.26	1.9	0.6
F	<0.1	0.19	0.12
Al	4.5	16	10
Fe	<5	60	15
Mn	<0.3	29	2.2
Cu	<1	<1	<1
Zn	<0.2	0.47	0.21
Pb	<0.1	<0.1	<0.1
Mo	<0.5	1.7	0.71
Sb	<0.01	0.14	0.015
As	<0.03	0.48	0.12
Th	0.02	0.062	0.032
U	0.12	0.58	0.27
Li	<0.5	5.9	1.6
Ba	4.8	35	18
Sr	39	581	169
V	<0.5	1.7	0.43
Sc	14	35	19
Rb	0.052	0.65	0.16
Y	0.034	0.13	0.053
Zr	<0.05	0.42	0.067
La	<0.005	<0.005	<0.005
Br	<3	<3	<3
I	<0.2	3.9	0.51

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

μg/l, respectively. Alkalinity values are moderately high and ranges from 30 to 180 mg/l as HCO_3^- with a mean of 101 mg/l. The moderately high alkalinity is probably due to the presence of calcareous zones in the unit. These values of alkalinity suggest that the waters of mountainous headwater areas underlain by the Mancos Shale have moderate acid-neutralizing capacity to introduced acidification. Except for the moderately high dissolved solid content, the water quality is good.

Mesozoic sedimentary rocks

Waters were collected from one stream and four springs along the top and eastern flank of the Uncompahgre Plateau in the Uncompahgre National Forest (fig. 13). The ranges and means of selected species in water are shown in Table 11. The area is underlain by Cretaceous, Jurassic, and Triassic sedimentary rocks. Dominant units include Cretaceous Dakota Group and Burro Canyon Formation, Jurassic Summerville Formation, Entrada Sandstone, and Morrison Formation, and Triassic Wingate and Chinle Formation (Tweto, 1979). The rocks are mostly sandstone, siltstone, mudstone, and conglomerate. The rocks are dominantly terrestrial in origin and are mostly fluvial, but dune, flood-plain, and lacustrine deposits also occur. Many of the rocks were deposited during warm dry conditions. A few rocks of marine origin are included and consist of shale and limestone. Several of the units, such as the Morrison, Entrada, and Chinle Formations, contain uranium and vanadium deposits, particularly along the western flank of the Uncompahgre Plateau outside of the Uncompahgre National Forest. Impure coal beds are present in the Dakota Group. Relief ranges from moderate along the top to high along the flanks of the plateau. Annual precipitation ranges from 16 to 25 inches (Colorado Climate Center, 1984). Dominant vegetation is mainly subalpine forest, although scrublands occur along the lower slopes.

The sites contain Ca^{2+}- HCO_3^- type waters with alkaline pH values and moderately high conductivity values. The range in pH values is 7.48 to 8.53 with a mean of 7.94. The range in conductivity values is 299 to 527 μS/cm with a mean of 413 μS/cm. Mean Cl concentration is 3.5 mg/l, suggesting that waters have been in contact with rocks and some evaporation and concentration has taken place. Four of the samples are groundwater from springs. Mean SiO_2 concentration is 10.9 mg/l, which is low compared to average fresh water (Table 8), probably because of the larger grain size and well crystallized mineral grains which make up many of the units such as the sandstone. The mean concentrations of trace elements Zn, Cu, Mo, and As are low at 0.23, <1, <0.5, and 1.2 μg/l, respectively, but the mean concentrations of U and As are elevated at 2.7 and 1.2 μg/l, respectively. Uranium and vanadium deposits are present in some of the rock units, particularly along the western flank of the Uncompahgre Plateau, mainly outside

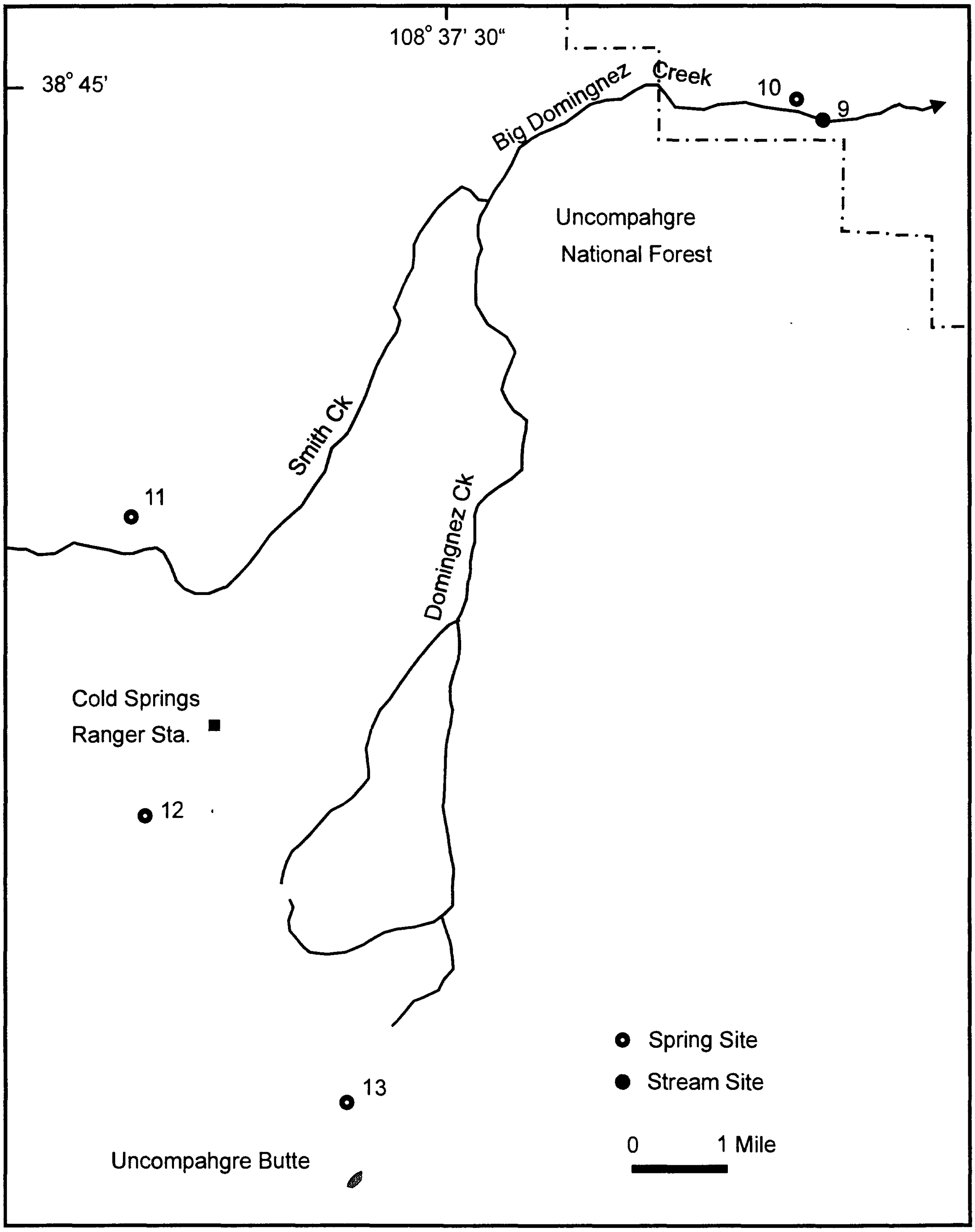

Figure 13. Site locations of stream and spring waters from areas underlain by Mesozoic sedimentary rocks along the top and east flank of the Uncompahgre Plateau, Uncompahgre National Forest.

Table 11. Five waters from Mesozoic sedimentary rocks of sandstone, mudstone, siltstone, shale, limestone, and conglomerate

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	299	527	413
pH	7.48	8.53	7.94
Ca	43	84	59
Mg	7.4	14	10
Na	2	15	5.2
K	1.3	2.8	1.8
SiO_2	6.9	19	10.9
Alkalinity	152	262	205
SO_4	2.5	7.9	4.7
Cl	1.6	6.1	3.5
F	<0.1	0.15	0.12
Al	<3	18	6.7
Fe	<5	25	4.6
Mn	<0.3	3.9	0.68
Cu	<1	1	<1
Zn	<0.2	0.29	0.23
Pb	<0.1	1.7	0.13
Mo	<0.5	0.65	<0.5
Sb	<0.01	0.086	0.019
As	0.33	2.8	1.2
Th	0.045	0.094	0.07
U	1.4	5.8	2.7
Li	7.9	20	12
Ba	227	439	286
Sr	161	535	241
V	<0.5	2.7	0.68
Sc	11	25	15
Rb	1.5	4	2.4
Y	<0.03	0.2	0.035
Zr	<0.05	0.44	0.14
La	<0.005	0.064	0.005
Br	<3	78	8
I	<0.2	5.5	0.98

[1]Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l
[2]All variables are geometric means except for pH which is arithmatic mean.

the National Forest. The mean concentrations of Al, Fe, and Mn are low at 6.7, 4.6, and 0.68 μg/l respectively. Alkalinity values are high and range from 152 to 262 mg/l as HCO_3^- with a mean of 205 mg/l. The high alkalinity values are probably because of the presence of fine-grain, poorly crystallized calcite in marlstones, lacustrine deposits and as cements in sandstones. The high alkalinity values ensure that the waters from this area have good acid-neutralizing capacities to introduced acidification. Overall the waters are moderately high in total dissolved solids for headwater areas, but otherwise are of good chemical quality.

Paleozoic sedimentary rocks

Waters were collected from 14 streams and one spring in the Cement Creek and Spring Creek drainages along the western flank of the Sawatch Range, Gunnison National Forest (fig. 14). The ranges and means of selected species in water are shown in Table 12. The area is underlain by Paleozoic sedimentary rocks. Dominant units include Permian and Pennsylvanian Maroon Formation, Pennsylvanian Minturn and Belden Formations, Mississippian Leadville Limestone, Williams Canyon Formation, and Manitor Limestone, and Cambrian Sawatch Quartzite (Tweto, 1976). The rocks are mostly limestone, dolomite, arkosic sandstone, conglomerate, and shale. Relief is high and annual precipitation ranges from 25 to 40 inches (Colorado Climate Center, 1984). Dominant vegetation is mainly subalpine forest.

The sites contain 14 Ca^{2+}- HCO_3^- and one Ca^{2+}- SO_4^{2-} type waters with alkaline pH values and high conductivity values. The range in pH is 7.97 to 8.59 with a mean of 8.30. The range in conductivity values is 225 to 659 μS/cm with a mean of 356 μS/cm. Mean Cl concentration is <0.25 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 SiO_2 concentration is 6.3 mg/l which is low compared to average fresh water (Table 8), probably because of the larger grain size and well crystallized mineral grains of the silicate minerals and the abundance of carbonate minerals. The sulfate concentrations range from 0.85 to 204 mg/l, with a mean of 13.5 mg/l. Seven sites had sulfate concentrations > 30 mg/l and two sites had concentrations >100 mg/l. The high concentrations of sulfate are probably due to the dissolution of gypsum present in the Permian and Pennsylvanian rocks. The Evaporite Facies to the north of the Gunnison National Forest contains gypsum and intertongues with the Minturn and Lower Maroon Formations (Tweto, 1976). The sites with sulfate >100 mg/l are from drainages within these units. The mean concentrations of trace elements Zn, Cu, Mo, and As are low at 0.6, <0.5, <0.41, and <3 μg/l, respectively. The mean concentrations of Al, Fe, and Mn are low at 0.34, <20, and 0.6 μg/l respectively. Alkalinity values are high and range from 110 to 194 mg/l as HCO_3^- with a mean of 143 mg/l. The moderately high alkalinity values are probably because of

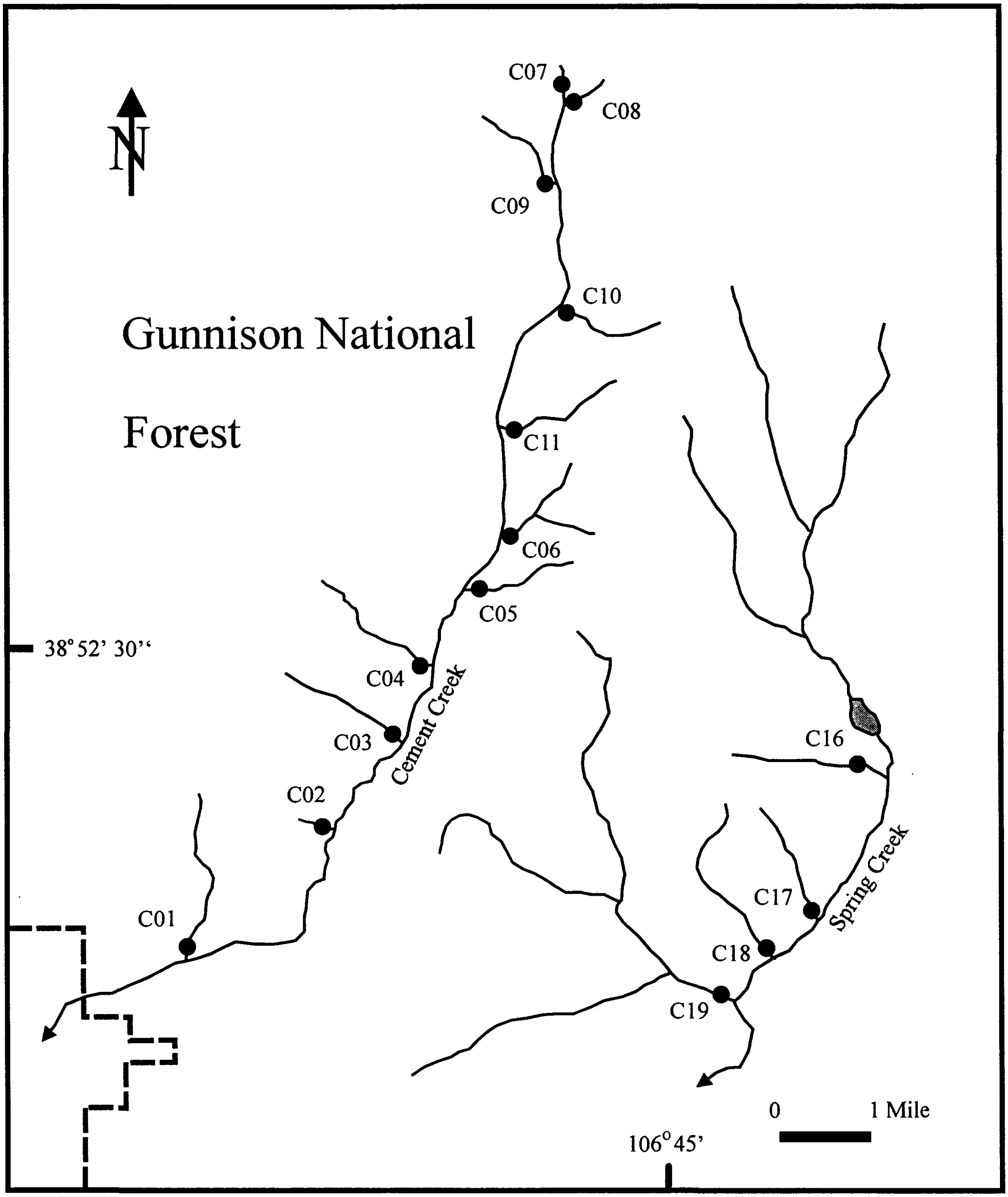

Figure 14. Site locations of stream and spring waters collected from watersheds underlain by Paleozoic sedimentary rocks in the Cement Creek watershed, Gunnison National Forest.

Table 12. Fourteen stream waters and one spring water from watersheds underlain by Paleozoic sedimentary rocks

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	225	659	356
pH	7.97	8.59	8.30
Ca	40.6	101	52.6
Mg	2.94	25	11
Na	0.61	5.4	1.3
K	0.11	1.3	0.47
SiO_2	3.7	12	6.31
Alkalinity	110	194	143
SO_4	0.85	204	13.5
Cl	<0.25	1.7	<0.25
F	<0.1	0.2	<0.1
Al	0.77	7.7	0.34
Fe	<20	61	<20
Mn	0.1	29	0.6
Cu	<0.5	0.7	<0.5
Zn	<0.5	4.7	0.6
Pb	<0.05	<0.05	<0.05
Mo	<0.25	1.5	0.41
Sb	<0.01	0.2	<0.1
As	<3	<3	<3
Th	<0.005	0.02	0.01
U	<0.001	1.2	0.56
Li	0.6	15	2.1
Ba	54	264	88.5
Sr	26	107	107
V	0.7	1.8	0.9
Sc	0.6	1.3	0.9
Rb	0.5	3.1	0.47
Y	<0.01	0.1	0.03
Zr	<0.05	<0.05	<0.05
La	<0.01	0.02	<0.01

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

the presence of abundant carbonate rocks and carbonate cement of some of the clastic rocks. The moderately high alkalinity values ensure that the waters from this area have good capacities to neutralize effects from introduced acidification. Overall the waters are moderately high in total dissolved solids, but otherwise are of good chemical quality.

Tertiary and Proterozoic intrusive rocks and Proterozoic metamorphic rocks

Water samples were collected from seven streams and one spring along the western flank of the Sawatch Range in the Quartz Creek area (fig. 15) and Tomichi Creek area (fig. 16) in the Gunnison National Forest. The ranges and means of selected species in water are shown in Table 13. The areas are underlain by Proterozoic granites and felsic and hornblende gneiss and Oligocene stocks and dikes. The Proterozoic rocks are a basement complex of mainly metamorphic gneiss which has been intruded by granitic rock. Most of the rocks are felsic in composition and all are considered together as one group. The areas are of high relief and annual rainfall ranges from 16 to 35 inches (Colorado Climate Center, 1984). Vegetation is mainly subalpine forest. The sites all contain dilute Ca^{2+}- HCO_3^- type waters with slightly acidic to alkaline pH values. Values of pH range from 6.89 to 8.18 with a mean of 7.82. Conductivity values are low and range from 47 to 126 μS/cm with a mean of 83 μS/cm. The mean Cl concentration is 0.39 mg/l, which suggests that the waters, which contain significant snow melt, are in short contact with the rocks, as would be expected for these dominantly crystalline rocks, with poorly developed soil zones and poor reserves of groundwater. In addition, the felsic rock composition and the well crystallized nature of the minerals ensure that chemical weathering is slow. Mean SiO_2 concentration is 14 mg/l and is about average for fresh water (Table 8). Even though the rocks are felsic in composition, the medium to coarse grain size and the well crystallized nature of the rock minerals, ensure that the SiO_2 concentrations in waters are not higher. Sulfate concentrations range from 1 to 15 mg/l with a mean of 3.5 mg/l. The higher values of some waters (appendix 1) are probably due to oxidation of pyrite present in areas of weakly mineralized rocks. Mines are present in the area, but no significant mining is present in the sampled watersheds. The mean concentrations of Cu and As are low at <1 and <0.03 μg/l, respectively. The mean concentrations of Zn, Mo and U at 0.64, 0.83 and 0.78 μg/l, respectively, are slightly elevated compared to other rock types in this study, probably due to the presence of weakly mineralized rocks in some of the watersheds. The mean concentrations of Al, Fe, and Mn are low at 14, 13, and 0.3 μg/l, respectively. Alkalinity values range from 20 to 50 mg/l as HCO_3^- with a mean of 34 mg/l. The low mean alkalinity value indicates that the rocks have low capacity to neutralize introduced acidity. The chemical quality of the waters evolving within these rocks is excellent.

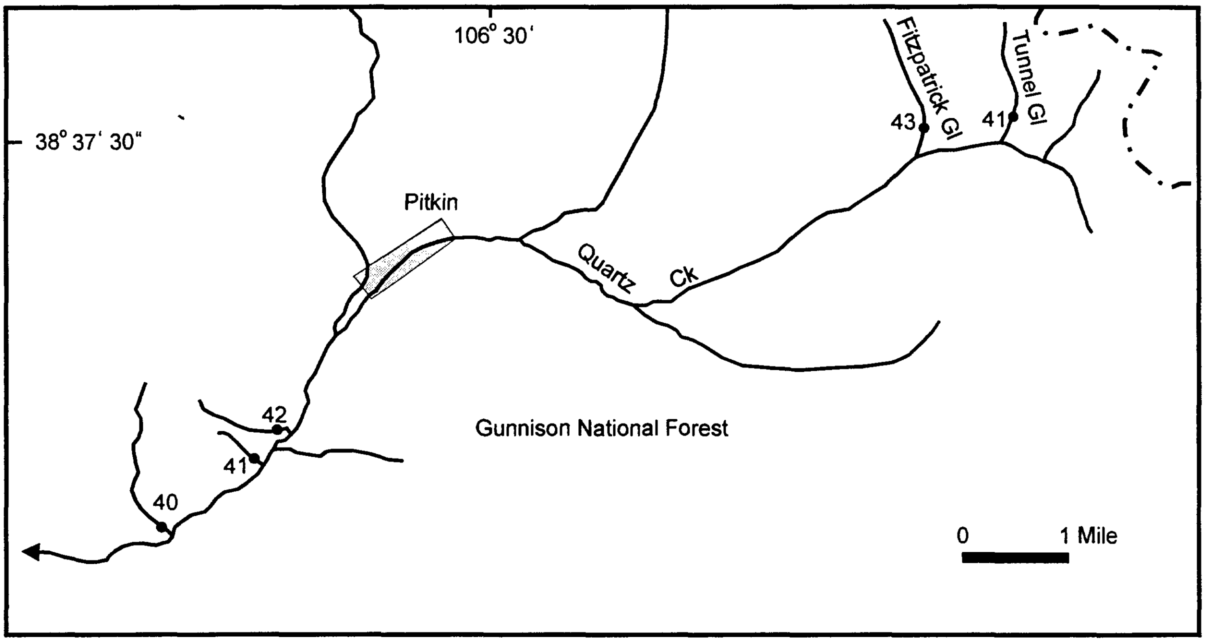

Figure 15. Site locations for stream waters from areas underlain by Tertiary and Proterozoic intrusive rocks and Proterozoic metamorphic rocks in the Quartz Creek area, Gunnison national Forest.

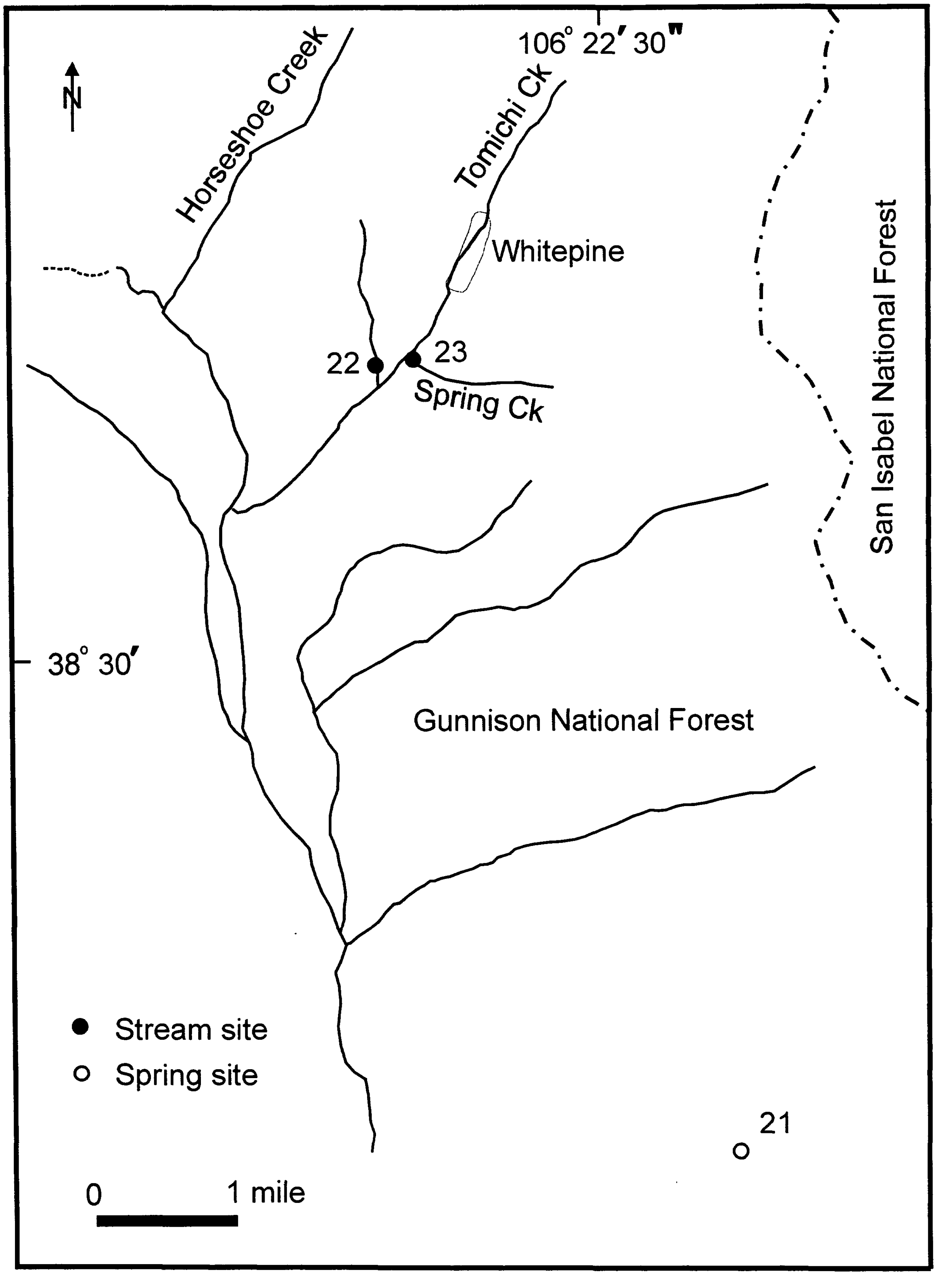

Figure 16. Site locations for stream and spring waters from areas underlain by Proterozoic intrusive rocks and Proterozoic metamorphic rocks along the western flank of the Sawatch Range, Gunnison National Forest.

Table 13. Eight waters from Tertiary and Proterozoic granite and quartz monzonite and Proterozoic felsic and hornblende gneiss.

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	47	126	83
pH	6.89	8.18	7.82
Ca	5.8	12	8
Mg	0.51	4.1	1.7
Na	1.2	5.3	3.1
K	0.24	0.84	0.55
SiO_2	6.1	22	14
Alkalinity	20	50	34
SO_4	1	15	3.5
Cl	<0.25	0.9	0.39
F	<0.1	2.2	0.21
Al	5.1	47	14
Fe	<5	35	13
Mn	<0.3	0.49	<0.3
Cu	<1	1	<1
Zn	0.22	5.1	0.64
Pb	<0.1	1.3	0.2
Mo	<0.5	2.9	0.83
Sb	<0.01	0.15	0.015
As	<0.03	<0.03	<0.03
Th	0.023	0.37	0.077
U	0.17	7.3	0.78
Li	0.68	5.7	1.7
Ba	2.6	29	8.7
Sr	28	48	37
V	<0.5	0.57	<0.5
Sc	<10	30	20
Rb	0.12	1.5	0.35
Y	<0.3	0.77	0.17
Zr	0.084	12.5	0.35
La	<0.005	0.57	0.036
Br	<3	<3	<3
I	<0.2	3.2	0.22

[1]Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l

[2]All variables are geometric means except for pH which is arithmatic mean.

Comparison of Water Chemistry from each of the Ten Rock Types

The chemistry of water evolving in the mountainous headwater areas depend on the chemical composition of the underlying rock type. A unique range of water chemistry evolves within each rock type For the ten rock compositional types in this study, the means of selected species and other parameters are shown in Table 14. A discussion follows concerning rock compositional types and selected variables and species.

Total dissolved solids (TDS) values can be used to compute rock weathering rates at which rivers transport chemical weathering products to the ocean. The TDS values can be used to compare waters from different geologic terrains as a means of comparing chemical weathering rates. TDS values are calculated by recalculating the bicarbonate ion in terms of carbonate in the solid phase and summing the remaining chemical data. The bicarbonate ion is converted to carbonate in the solid phase because the bicarbonate ions were derived from the atmosphere rather than rocks (Hem, 1992). Mean TDS values for waters from the ten rock types are shown in Table 14. Waters with the highest mean TDS values evolve from areas underlain by Mesozoic sedimentary rocks followed by Tertiary sedimentary rocks. Dissolved solids in the waters depend on the rock compositional type, but also time of contact of the waters and rocks and evaporation effects. One way to minimize the time of contact and evaporation effects is by normalizing TDS values by dividing by the Cl content for each site. This assumes that Cl content is conservative and there is no addition of Cl to the waters by the dissolution of minerals containing Cl (such as halite). Table 15 shows the results of normalizing the TDS values. The waters with the highest normalized TDS values are from areas underlain by Paleozoic sedimentary rocks followed by the Mancos Shale, Tertiary sedimentary rocks, and the Mesaverde Formation. The waters with the lowest normalized TDS values are from areas underlain by Mesozoic sedimentary rocks and Tertiary ash-flow tuff. The Paleozoic sedimentary rocks are undergoing the most rapid potential rate of chemical weathering, supplying the most dissolved solids to the waters of the area. Potential release of TDS is used to indicate that chemical weathering and the release of TDS is dependent on amounts of precipitation. Variation in amounts of precipitation will affect the rate of chemical weathering. Potential release of TDS does not take into account the amount of precipitation of an area. The probable presence of gypsum in the Paleozoic sedimentary rocks is a major contributor to the TDS of waters evolving in rocks underlain by these rocks. The Mesozoic sedimentary rocks and the Tertiary ash-flow tuff are undergoing the lowest potential rate of chemical weathering and supplying the lowest amounts of dissolved solids to the waters of the area. The Mesozoic sedimentary rocks contain abundant well crystallized silica minerals that are resistance to weathering. The Tertiary ash-

Table 14. Summary of chemical composition of waters from various rock types, Grand Mesa, Uncompahgre, and Gunnison National Forests, Colorado

Dominant Rock Compositonal Type	Setting	Relief	Precipitation annual, inches	Dominant Vegetation
Tertiary basalt flows and associated rocks	Grand Mesa	low	30 to 45	subalpine forest, grassland
Tertiary felsic ash-flow tuff	San Juan volcanic field	high	16 to 30	subalpine forest
Tertiary quartz latitic lava and breccia	San Juan volcanic field	high	16 to 25	subalpine forest
Tertiary andesitic lava, breccia, tuff	West Elk volcanic field	high	20 to 40	subalpine forest
Tertiary sedimentary rocks	Battlement and Grand Mesa	moderate	20 to 35	subalpine forest, oak scrublands
Cretaceous Mesaverde Formation	Piceance basin and Elk Mountains	high	20 to 35	subalpine forest
Cretaceous Mancos Shale	San Juan volcanic field and Paradox basin	high	16 to 40	subalpine forest
Mesozoic sedimentary rocks	Uncompahgre uplift	high	16 to 25	subalpine forest
Paleozoic sedimentary rocks	west flank Sawatch Range	high	25 to 40	subalpine forest
Tertiary and Proterozoic felsic and intermediate intrusive and Proterozoic metamorphic rocks	Sawatch Range	high	16 to 35	subalpine forest

Number	Dominate water type	TDS	pH	Conductivity uS/cm	Ca ppm	Mg ppm	Na ppm	K ppm	SiO2	Alkalinity ppm	SO4 ppm	Cl ppm	F ppm	Al ppb
4	Ca, HCO3	39.3	7.41	63	5.4	2.1	1.8	0.37	14	28	0.65	0.29	<0.10	54
5	Ca, HCO3	74.5	7.43	100	11	1.7	4.4	1.3	29	46	2.7	0.88	0.10	16
4	Ca, HCO3	93	7.48	124	12.6	1.8	6.9	1.1	30.8	36	16.6	0.56	<0.1	55
8	Ca, HCO3	109	7.99	158	16	3	7.7	1.7	35	72	3.5	0.7	<0.10	13
7	Ca, HCO3	196	8.50	365	39	12	15	1.4	18	191	8.1	1.4	0.16	12
8	Ca, HCO3	69.5	8.31	126	13	3	5.4	0.49	13	54	5.3	0.49	0.11	12
10	Ca, HCO3	134	8.20	258	32	7.5	4.7	0.36	14	101	18	0.60	0.12	10
5	Ca, HCO3	200	7.94	413	59	10	5.2	1.8	11	205	4.7	3.5	0.12	6.7
15	Ca, HCO3	174	8.30	356	52.6	11.0	1.3	0.47	6.3	143	13.5	<0.25	<0.1	0.34
8	Ca, HCO3	50.9	7.82	83	8	1.7	3.1	0.55	14	34	3.5	0.39	0.21	14

Fe	Mn	Cu	Zn	Co	Mo	Ni	Cr	As	Sb	W	Pb	U	Th	Li	Be
ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
91	15	<1	0.40	<0.5	<0.5	<2	<0.1	0.048	0.017	0.20	0.15	0.069	0.083	<0.5	<0.05
65	2.9	<1	0.24	<0.5	<0.5	<2	<0.1	1.2	0.021	<0.01	0.12	0.058	0.19	1.5	<0.05
60	2.7	0.56	0.5	0.06	0.41	0.4	<1	<3	<0.1	<0.02	<0.05	0.140	0.03	3.6	<0.05
16	0.48	<1	0.22	<0.5	<0.5	<2	<0.1	0.7	0.012	<0.01	<0.10	0.092	0.2	1.3	<0.05
13	4.7	<1	0.22	<0.5	1.9	<2	<0.1	1.9	0.12	0.018	0.18	1.4	0.36	7.2	<0.05
14	2.0	<1	0.24	<0.5	<0.5	<2	<0.1	0.08	<0.010	0.01	<0.10	0.13	0.038	1.4	<0.05
15	2.2	<1	0.21	<0.5	0.71	<2	<0.1	0.12	0.015	<0.01	<0.10	0.27	0.032	1.6	<0.05
<5	0.68	<1	0.23	<0.5	<0.5	<2	<0.1	1.2	0.019	<0.01	0.13	2.7	0.07	12	<0.05
<20	0.57	<0.5	0.6	0.06	0.41	1.2	2.6	<3	<0.1	0.02	<0.05	0.56	0.01	2.1	<0.05
13	<0.3	<1	0.64	<0.5	0.83	<2	<0.1	<0.03	0.015	0.03	0.2	0.78	0.077	1.7	<0.05

Ba	Ti	Sc	V	Se	Br	I	Sr	Rb	Y	Zr	Cs	La	Ce
ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
14	2.1	21	<0.5	<0.2	<3	0.98	36	0.50	0.41	0.43	<0.002	0.25	0.43
18	<2	35	1.2	<0.2	3.5	2.2	79	1.2	0.10	0.51	<0.002	0.024	0.035
4.6	1.8	2.9	1.1	<5	n.d.	n.d.	115	1.4	0.32	0.3	0.03	0.13	0.17
5	<2	41	2.2	<0.2	<3	0.21	95	2.4	0.071	0.28	<0.002	<0.005	0.016
62	<2	25	2.8	<0.2	6.6	1.5	311	0.60	0.083	0.42	<0.002	0.017	0.071
18	<2	18	<0.5	<0.2	<3	<0.2	102	0.32	0.042	0.15	<0.002	<0.005	0.006
18	<2	19	0.43	<0.2	<3	0.51	169	0.16	0.053	0.067	<0.002	<0.005	<0.005
286	<2	15	0.68	0.27	8	0.98	241	2.4	0.035	0.14	0.056	0.005	<0.005
88.5	0.3	0.9	0.9	<5	n.d.	n.d.	107	0.47	0.03	<0.05	0.01	<0.01	<0.01
8.7	<2	20	<0.5	<0.2	<3	0.22	37	0.35	0.17	0.35	0.002	0.036	0.033

Table 15. Normalized values for selected parameters and species of waters from watersheds within GMUG.

	Chloride	TDS	TDS/Cl	Alkalinity	Alkalinity/Cl
Tertiary basalt flows and associated rocks	0.29	39.3	133.8	28	97
Tertiary felsic ash-flow tuff	0.88	74.5	84.7	46	52
Tertiary quartz latitic lava and breccia	0.56	93	166	36	64
Tertiary andesitic lava, breccia, tuff	0.65	109.4	155.5	72	103
Tertiary sedimentary rocks	1.4	196	144.6	191	136
Cretaceous Mesaverde Formation	0.49	69.5	141.5	54	110
Cretaceous Mancos Shale	0.8	133.8	222.2	101	168
Mesozoic sedimentary rocks	3.4	200.3	58.1	205	59
Paleozoic sedimentary rocks	<0.25	174	714.6	143	572
Tertiary and Proterozoic intrusive and metamorphic rocks	0.39	50.9	131.5	34	87

Total dissolved solids(TDS) in mg/l, chloride, sulfate, and fluoride in mg/l, alkalinity in mg/l HCO_3, remaining elements in ug/l.

Sulfate	Sulfate/Cl	F	F/Cl	U	U/Cl	Li	Li/Cl
0.65	2.24	0.07	0.24	0.069	0.24	0.3	1.03
2.7	3.07	0.1	0.11	0.058	0.07	1.5	1.7
16.6	30	<0.1	0.125	0.14	0.25	3.6	6.4
3.5	5	0.07	0.1	0.092	0.13	1.3	1.86
8.1	5.79	0.16	0.11	1.4	1	7.2	5.14
5.3	10.82	0.11	0.22	0.13	0.27	1.4	2.86
18	30	0.12	0.2	0.27	0.45	1.6	2.67
4.7	1.34	0.12	0.03	2.7	0.77	12	3.43
13.5	54	<0.1	0.28	0.56	2.24	2.1	8.4
3.5	8.97	0.21	0.54	0.78	2	1.7	4.36

flow tuff is felsic in composition and more resistance to weathering than more mafic rocks.

Spacial maps are constructed showing the potential release of TDS by recalculating the normalized TDS values. The highest mean normalized TDS value is from Paleozoic sedimentary rocks and is assumed to be one. The recalculated mean normalized TDS values for the remaining rock compositional types are calculated by dividing by the highest mean normalized TDS value. Rankings of potential release of TDS are shown in Table 16. Maps showing potential release of TDS are made for each of the three National Forests by plotting the recalculated mean normalized TDS values from Table 16 by rock compositional types. The maps of potential release of TDS for the three National Forests are shown in figs. 17-19.

Mean values for pH of waters from areas underlain by the ten rock compositional types range from 7.41 for Tertiary basaltic rocks to 8.50 for Tertiary sedimentary rocks. The 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. Because pH of the waters are important for assessments of acidity of the watersheds, spacial maps were made of mean pH by plotting the mean pH values for each of the rock compositional types for each of the three National Forests (figs. 20-22).

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. Therefore in this study, alkalinity is the capacity of the water to react and consume acid. If an area is affected by acid mine drainage or acid rain, the alkalinity will consume the introduced acid until all the alkalinity is consumed. After this, if acidity is still being introduced, the acidity of the water will increase. So the alkalinity is a measure of the capacity of a watershed to resist the introduction of acidity. 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 ten rock types range from 28 to 205 mg/l as HCO_3^-. The waters with the highest alkalinity values are from areas underlain by Mesozoic sedimentary rocks. The waters with the lowest alkalinity values are from areas underlain by Tertiary basaltic rocks (Table 14). Alkalinity in the waters depends on the rock compositional type, but also time of contact of the rocks and water and evaporation effects. To decrease the effect of time of contact and evaporation effects, alkalinity is normalized using the Cl content in a manner similar to that done when normalizing TDS. This assumes that Cl content is conservative and there is no addition of

Table 16. Rankings of rock composition type as to potential release of TDS and acid neutralizing capacity to introduce acidity in the GMUG area

	Potential release of TDS		
Rock Composition	TDS	TDS/Cl	Recal TDS
Tertiary basalts	39.3	133.8	0.19
Tertiary felsic ash flow tuff	74.5	84.7	0.12
Tertiary latitic lava and breccia	93	166	0.23
Tertiary andisites	109.4	155.5	0.22
Tertiary Sedimentary rock	196	144.6	0.20
Mesaverde Formation	69.5	141.5	0.20
Mancos Shale	133.8	222.2	0.31
Mesozoic Sedimentary rock	200.3	58.1	0.08
Paleozoic Sedimentary rock	174	714.6	1.00
Tertiary and Proterozoic intrusive rocks	50.9	131.5	0.18

	Acid-Neutralizing Capacity		
Rock Composition	Alkalinity as mg/l HCO3	Normalized Alk (Alk/Cl)	Recalculated Normalized Alkalinity
Tertiary basalts	28	97	0.17
Tertiary felsic ash flow tuff	46	52	0.09
Tertiary latitic lava and breccia	36	64	0.11
Tertiary andisites	72	103	0.18
Tertiary Sedimentary rock	191	136	0.24
Mesaverde Formation	54	110	0.19
Mancos Shale	101	168	0.29
Mesozoic Sedimentary rock	205	59	0.1
Paleozoic Sedimentary rock	143	572	1
Tertiary and Proterozoic intrusive rocks	34	87	0.15

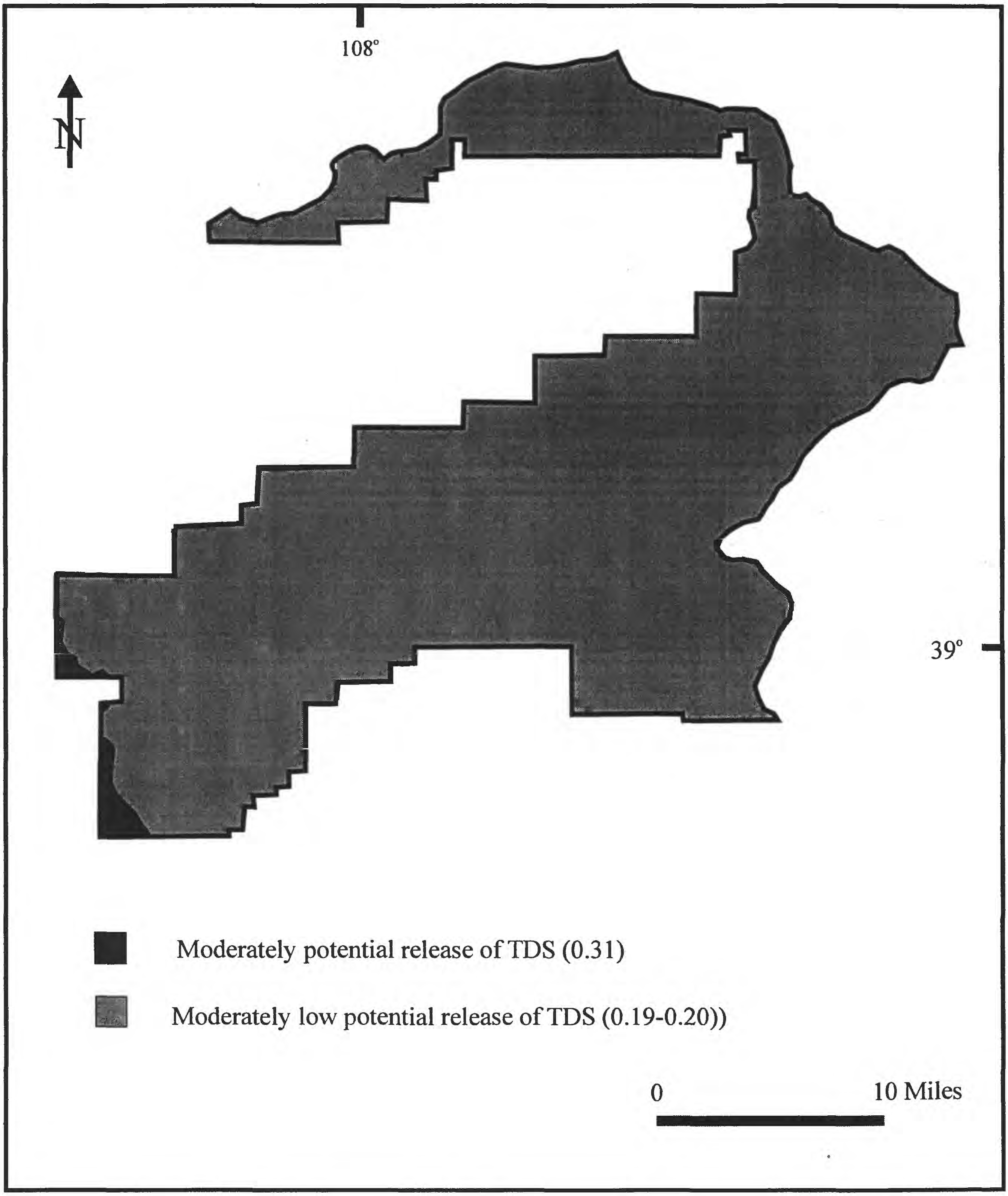

Figure 17. Potential release of total dissolved solids (TDS) in stream and spring waters, Grand Mesa National Forest.

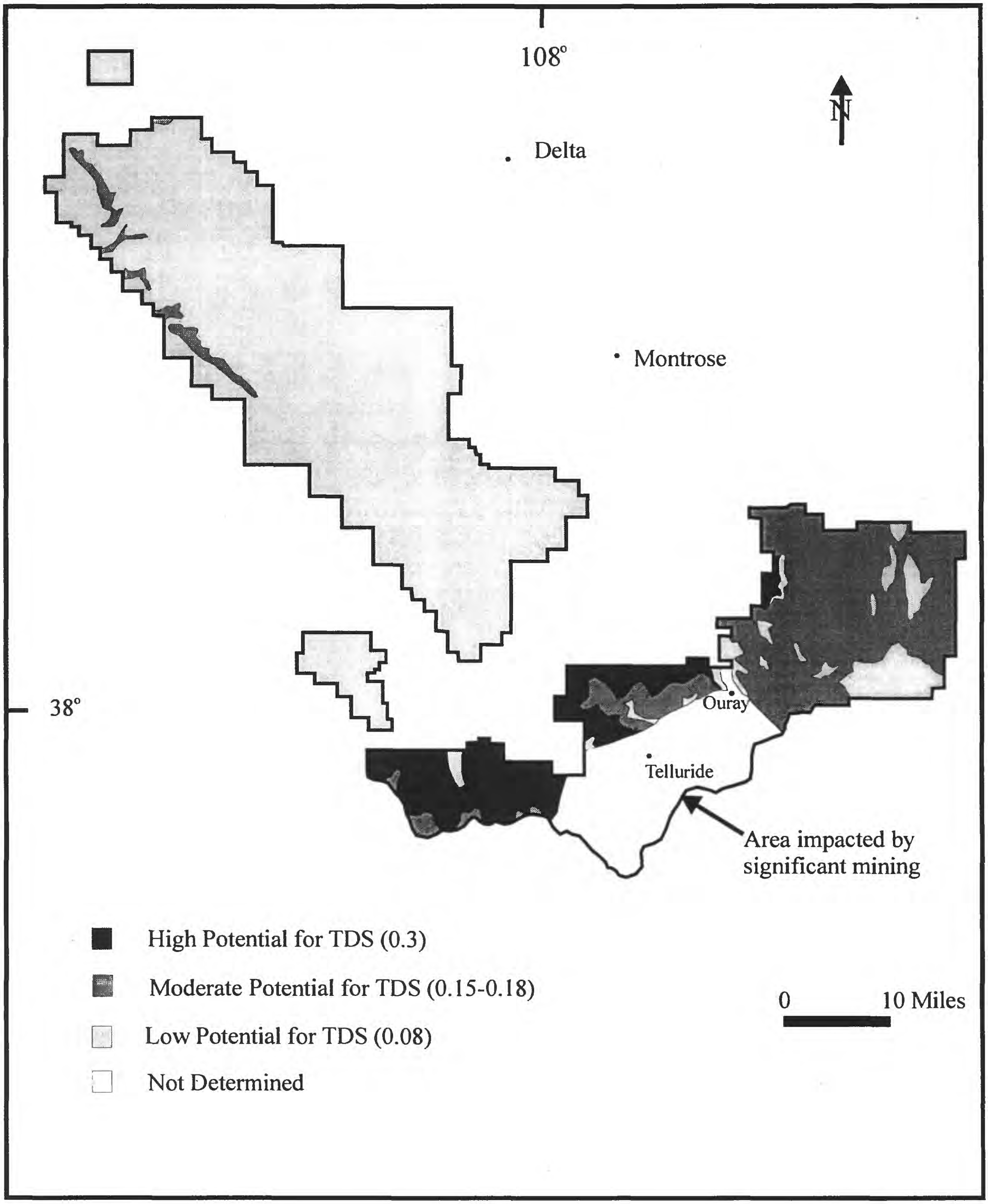

Figure 18. Potential for high total dissolved solids (TDS) in stream and spring waters, Uncomphagre National Forest, Colorado.

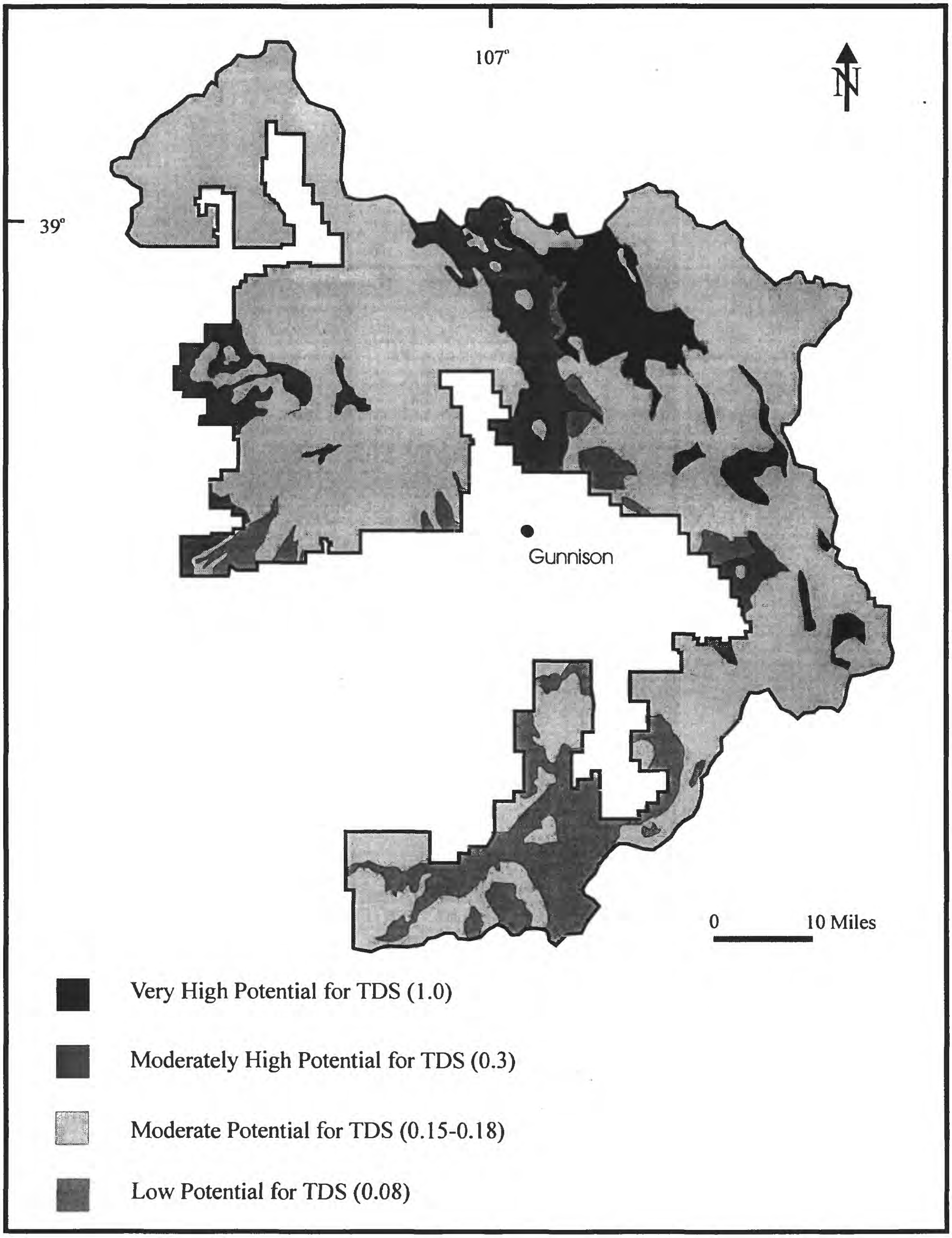

Figure 19. Potential for total dissolved solids (TDS) in stream and spring waters, Gunnison National Forest, Colorado.

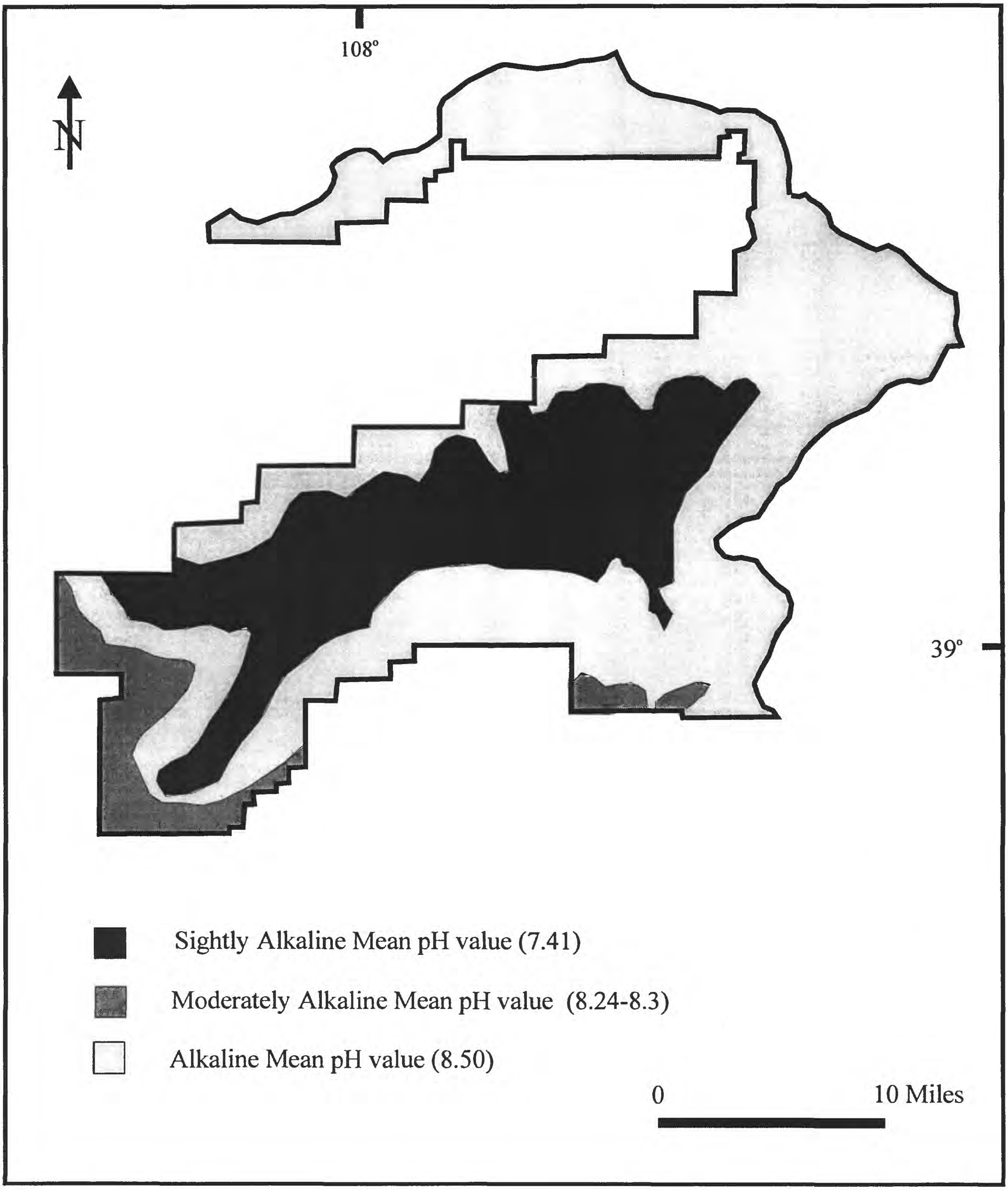

Figure 20. Mean pH values of stream and spring waters, Grand Mesa National Forest.

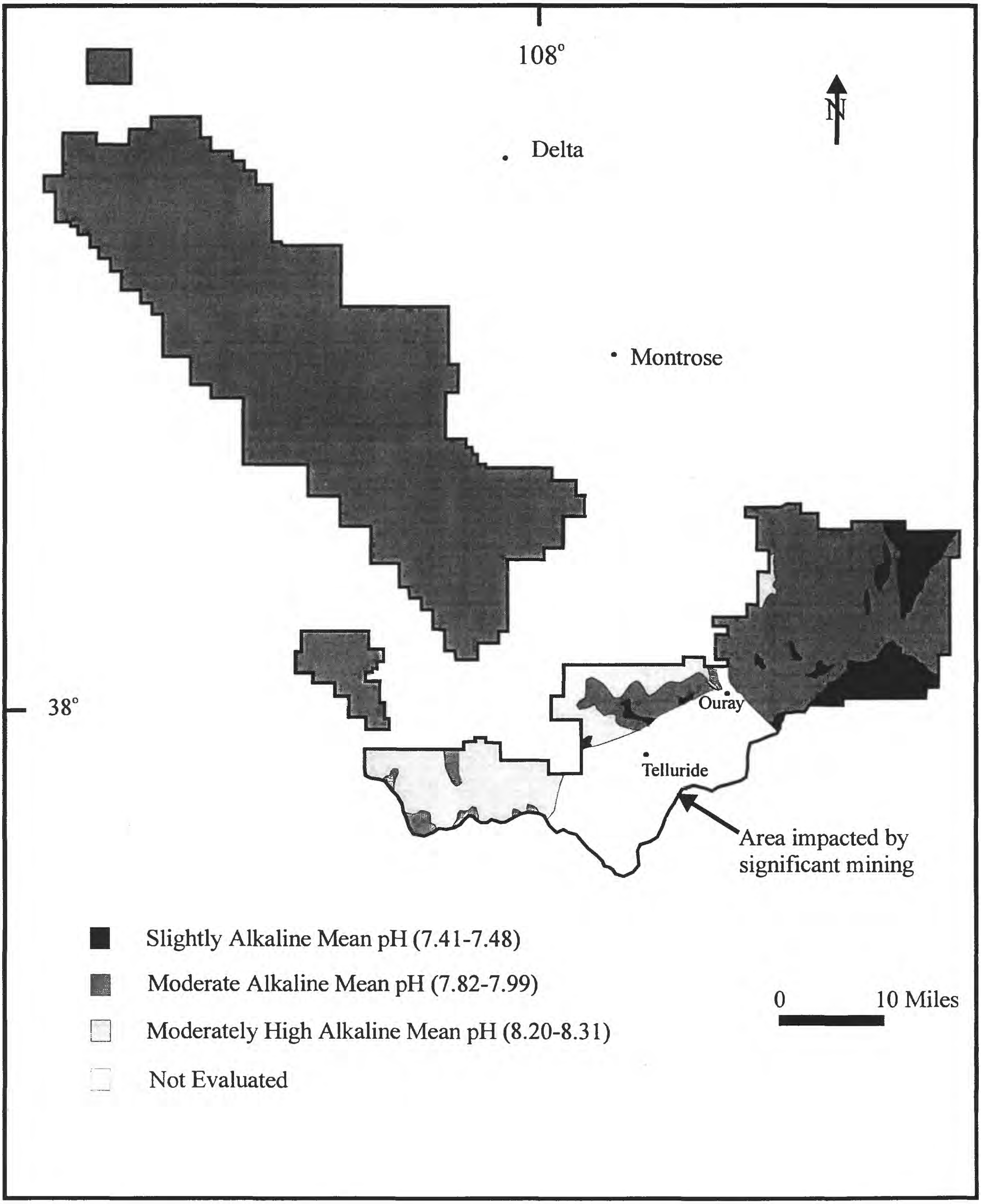

Figure 21. Mean pH values of stream and spring waters, Uncomphagre National Forest.

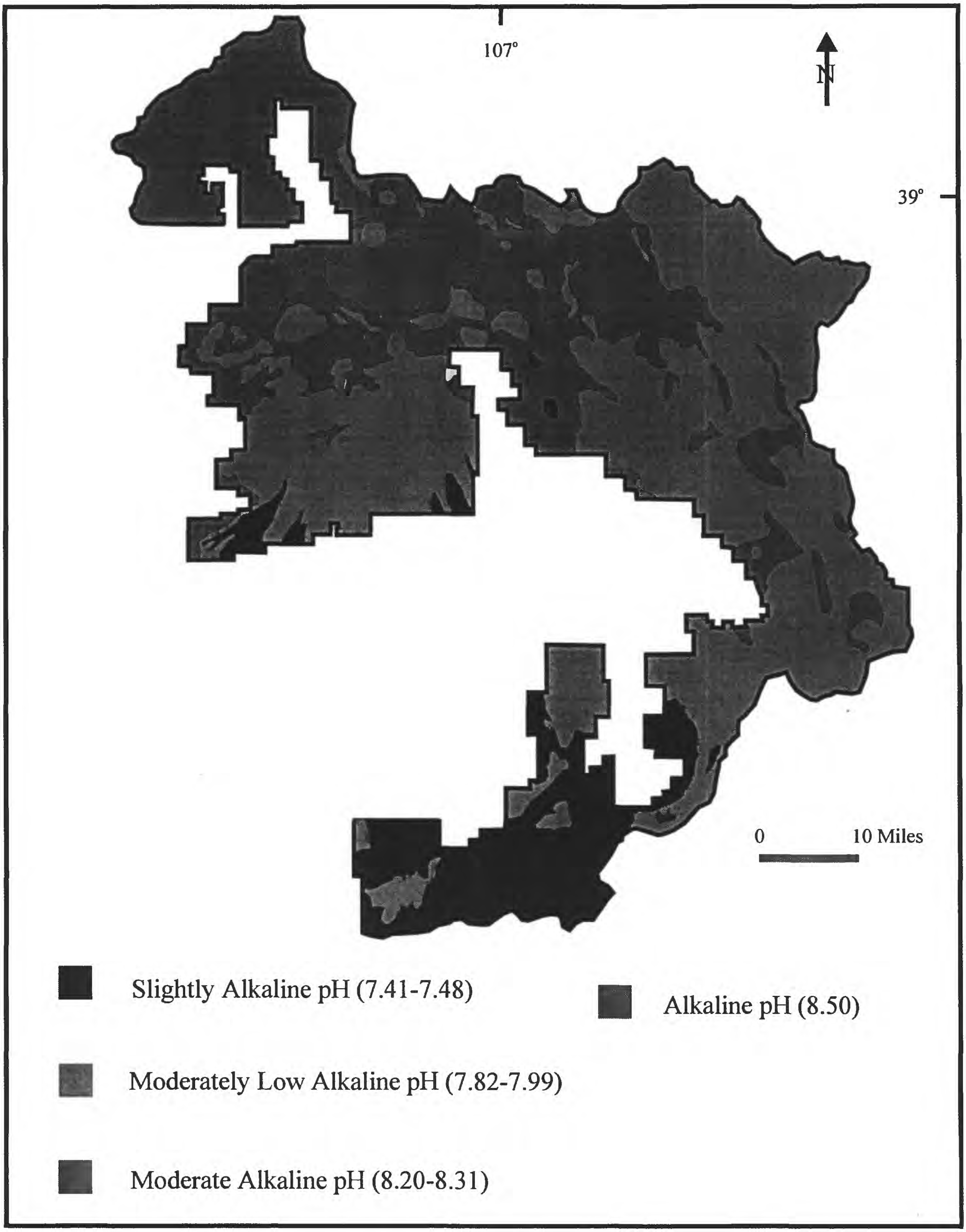

Figure 22. Mean pH values for stream and spring waters, Gunnison National Forest.

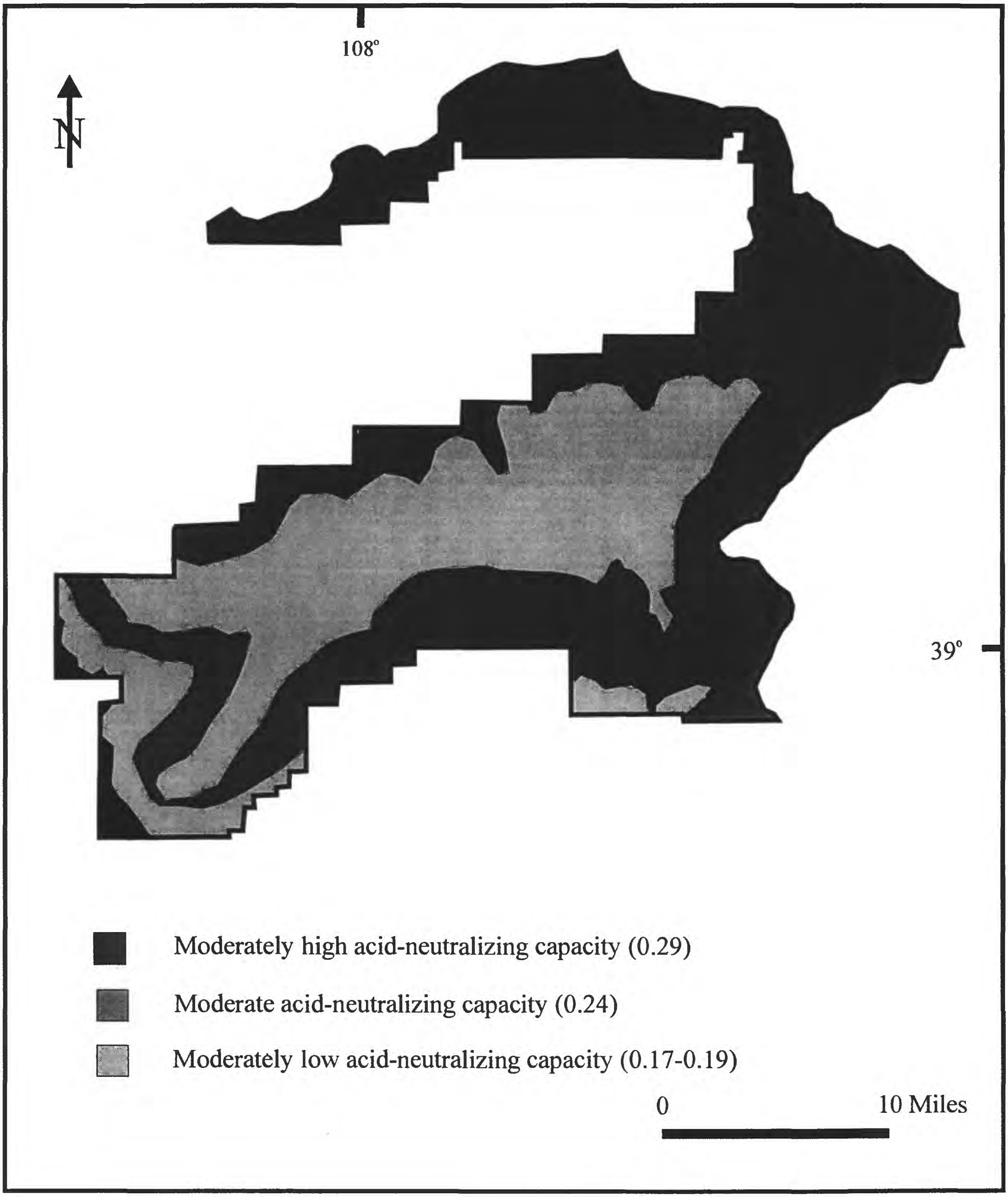

Figure 23. Acid-Neutralizing capacity to introduced acidity, Grand Mesa National Forest

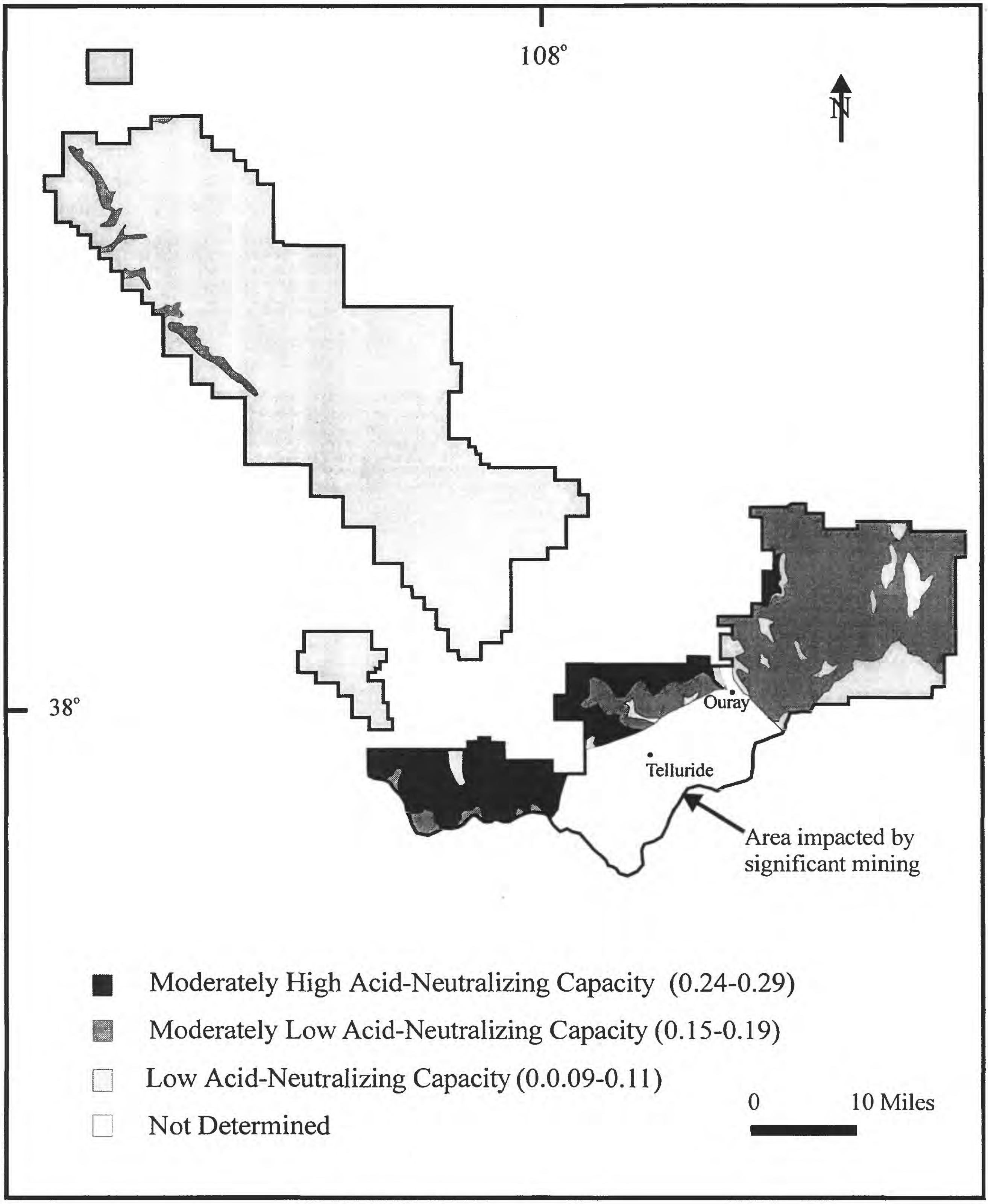

Figure 24. Acid-neutralizing capacity to introduced acidity, Uncomphagre National National Forest.

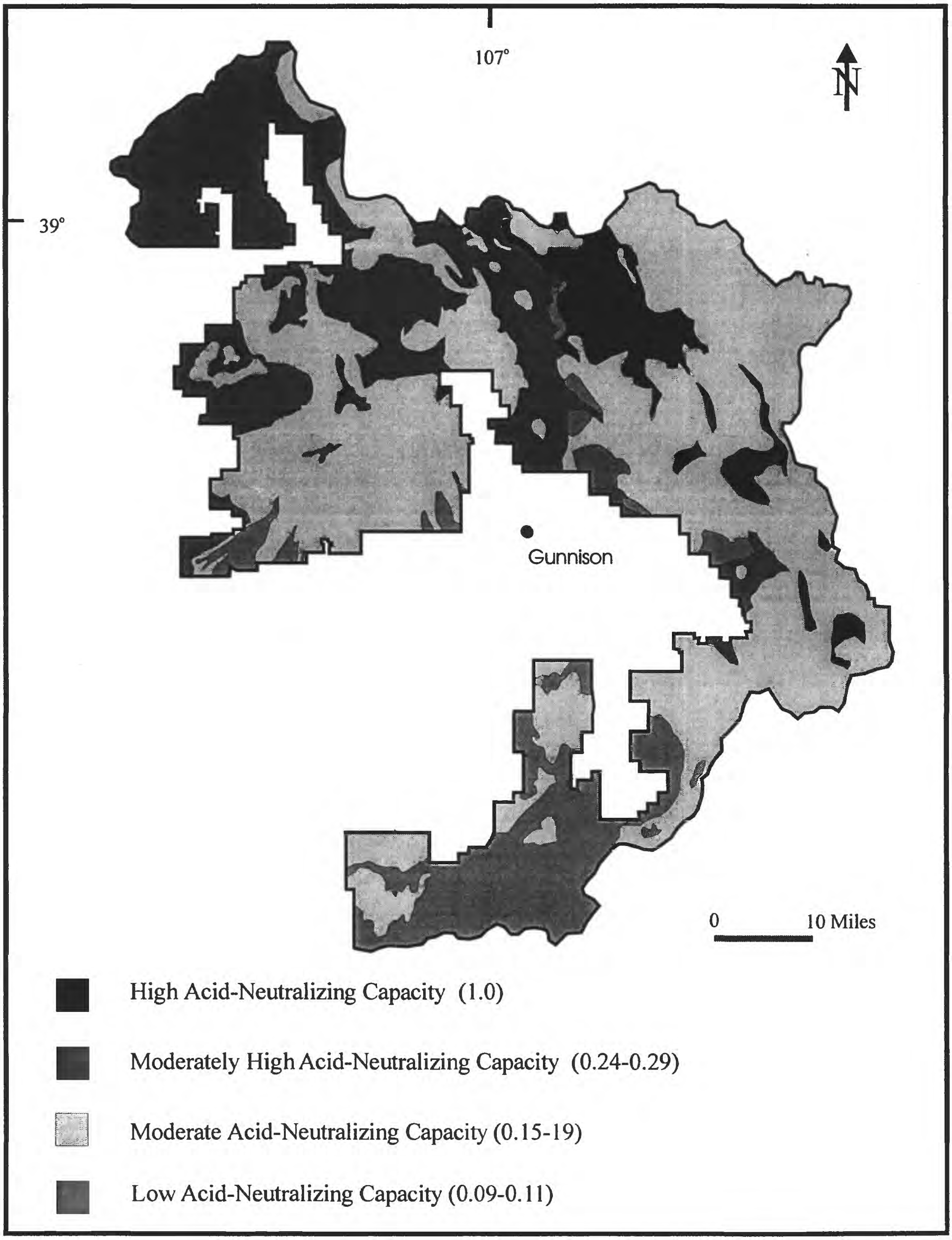

Figure 25. Acid-neutralizing capacity to introduced acidity, Gunnison National Forest.

dissolved solids to the waters by the dissolution of soluble salts containing Cl. The waters with the highest mean normalized alkalinity value are from areas underlain by Paleozoic sedimentary rocks, followed by the Mancos Shale and Tertiary sedimentary rocks (Table 15). The waters with the lowest mean normalized alkalinity values are from areas underlain by ash flow tuff. The normalized alkalinity value is a measure of the susceptibility of the watershed to resist introduced acidity.

Spacial maps are constructed showing acid-neutralizing capacity by recalculating the mean normalized alkalinity values. The highest mean normalized alkalinity value is from Paleozoic sedimentary rocks and is assumed to be one. The recalculated mean normalized alkalinity values for the remaining rock compositional types are calculated by dividing by the highest mean normalized alkalinity value. Rankings of acid-neutralizing capacities are shown in Table 16. Maps showing acid-neutralizing capacities are made for each of the three National Forests by plotting the recalculated mean normalized alkalinity values from Table 16 by rock compositional types. The maps of the three National Forests are shown in figs. 23-25.

Mean concentrations of silica in waters from areas underlain by the ten compositional rock types range from 11 mg/l for Mesozoic sedimentary rocks to 35 mg/l for Tertiary andesitic rocks (Table 14). Other high mean silica concentrations in waters are from areas underlain by Tertiary quartz latitic lava and breccia (31 mg/l) and ash flow tuff (29 mg/l). The high mean silica values are probably because these rocks contain fine-grained silicate minerals with high surface areas, particularly susceptible to the dissolution of silica. Conversely, the Mesozoic sedimentary rocks contain sandstone composed of larger sized and well crystallized mineral grains that have less surface areas. These grains are more resistant to silica dissolution.

Mean concentrations of waters from watersheds underlain by the ten rock types are all low in Cu, Zn, Co, Ni, Cr, Sb, Pb, and Be (Table 14). In addition, the mean values for Se are all < 0.2 μg/l except for waters from areas underlain by Mesozoic sedimentary rocks, for which the mean is 0.27 μg/l. Thus the contribution of Se in these mountainous headwater watersheds is very low. The Mancos Shale is known to be a source for Se concentrations in water, in the lower valleys, particularly in areas of irrigation (Wright and Butler, 1993). In these mountainous headwater streams in areas underlain by the Mancos Shale, evaporation effects are minimal and Se concentrations in waters are low.

Mean concentrations for Mo are low, except for a slightly elevated mean value in waters from areas underlain by Tertiary sedimentary rocks (1.9 μg/l). Mean concentrations for U are low, except for slightly elevated mean values in waters from areas underlain by Mesozoic sedimentary rocks (2.7 μg/l) and Tertiary sedimentary rocks (1.4 μg/l). Mean concentrations of As are low for waters from the three National Forests, except for waters from areas underlain by Tertiary sedimentary rocks (1.9 μg/l), Tertiary ash-flow tuff (1.2 μg/l), and Mesozoic sedimentary rocks (1.2 μg/l), all with slightly elevated mean values (Table 14).

Mean values for Al, Fe, and Mn are all low in waters from watersheds underlain by the ten rock compositional types except for elevated mean values for Al, Fe, and Mn in waters from areas underlain by Tertiary basaltic rocks (54, 91, and 15 μg/l, respectively), elevated Al and Fe from areas underlain by Tertiary quartz latitic lava and breccia (55 and 60 μg/l, and elevated mean Fe in waters from areas underlain by Tertiary ash flow tuff (65 μg/l) (Table 14).

Sulfate, F, and U and are mobile as anionic species in alkaline waters. These elements will concentrate in waters, depending on the time of contact of water and rock and evaporation effects. The highest mean sulfate concentration is in waters from areas underlain by the Mesaverde Formation at 18 mg/l (Table 14). The Mesaverde Formation contains coal with associated pyrite. The weathering of the pyrite is probably the source of the sulfate. To reduce the effects of evaporation and time of contact of water and rock, sulfate values are normalized by dividing by the Cl concentrations for each water sample and the means calculated. The highest mean normalized values for sulfate are waters from areas underlain by Paleozoic sedimentary rocks and the Mancos Shale followed by the Tertiary sedimentary rocks and the Mesaverde Formation (Table 15). The highest mean normalized sulfate value in waters from Paleozoic sedimentary rocks is probably due to the presence and dissolution of gypsum in the rocks. The high values in waters from the other rock compositional types are probably due to the weathering of pyrite, present in the sedimentary rocks.

The highest mean F concentration of 0.21 mg/l is in water from areas underlain by Tertiary intrusive and Proterozoic rocks (Table 14). The high concentrations of F in waters is probably because of the high F content of the Tertiary and Proterozoic intrusive rocks. When F is normalized in a manner similar to sulfate, these rocks are even more anomalous compared to the other major rock compositional types (Table 15). Interestingly, the Tertiary basaltic rocks are next highest in normalized F, which suggest that the basaltic rocks are elevated in F.

The highest mean U concentrations (Table 14) are in waters from areas underlain by Mesozoic sedimentary rocks (2.7 μg/l), Tertiary sedimentary rocks (1.4 μg/l), and Tertiary intrusives and Proterozic rocks (0.78 μg/l). When U is normalized, similar to sulfate, the highest values (Table 15) are in waters from areas underlain by Tertiary intrusive and Proterozoic rocks (2.00), Tertiary sedimentary rocks (1.00), and Mesozoic sedimentary rocks (0.77). These higher values suggest that these rock compositional types contain elevated concentrations of leachable U.

The highest mean Li values are in waters from areas underlain by Mesozoic sedimentary rocks with a mean of 12 μg/l, which is high compared to the remaining rock compositional types (Table 14). Much of the high mean Li concentration is due to the longer time of contact of water and rock and the evaporation effects of these mostly spring waters. If Li is normalized in a similar manner to that above, the waters with the highest mean normalized Li values are from Tertiary sedimentary rocks (5.14), followed by Tertiary intrusive and Proterozoic rocks (4.36), and Mesozoic sedimentary rocks (3.43) (Table 15).

When normalized so the effects of evaporation and time of contact of water and rock are minimized, the waters from watersheds underlain by Tertiary intrusive rocks and Proterozoic rocks are high in mean normalized F, U, and Li, compared to other rock compositional types in three National Forests. This suggests that these rocks are elevated in these elements, as would be expected for evolved felsic rocks.

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 stream 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, the cations in the stream waters occur mostly as simple cations and the anions as chloride, sulfate, carbonate, and bicarbonate complexes (Table 17). In addition, the state of saturation of the waters with mineral phases were calculated. Saturation indexes were 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 $SI<0$.

The input for the modeling was the mean values for each rock compositional type shown in Table 14. The waters from areas underlain by Tertiary sedimentary rocks, the Mancos Shale, Mesozoic sedimentary rocks, and Paleozoic sedimentary rocks are supersaturated with respect to calcite and dolomite (Table 18). These are headwater streams and not streams in the valleys where secondary calcite is abundant. Therefore the waters are in contact with dissolving carbonate minerals, such as calcite and dolomite present in these rock units. Another mineral which has an influence on the control of species in water is chalcedony. Most of the waters from all the rock compositional types are saturated or slightly oversaturated with respect to chalcedony (Table 18), which appears to control the amount of dissolved silica in the waters. Waters from Tertiary sedimentary rocks are oversaturated with respect to sepiolite (Table 18), which appears to control Mg mobility and may reflect the weathering of dolomite as the source for Mg.

Table 17. Speciation of selected elements in waters from GMUG.

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+}
Mn	Mn^{2+}, except Tertiary sediments as $MnCO_3^{0}$

Table 18. Saturation indices for selected minerals for waters from GMUG.

Rock composition type	Calcite	Dolomite	Siderite	Rhodochrosite	Chalcedony	Gypsum	Fluorite	Sepiolite	$Al(OH)_3$	CO_2
Tertiary basalt flows	-1.92	-4.09	-1.47	-1.97	**0.08**	-4.57	-4.06	-5.58	-0.75	-3.03
Tertiary felsic ash-flow tuff	-1.42	-3.54	-1.45	-2.51	**0.43**	-3.68	-3.43	-4.82	-1.2	-2.84
Tertiary quartz latitic lava, etc	-1.49	-3.76	-1.6	-2.66	**0.48**	-2.84	-3.65	-4.64	-0.58	-3.02
Tertiary andesitic lava, etc.	-0.57	-1.73	-1.42	-2.65	**0.45**	-3.38	-3.64	-2.14	-1.91	-3.18
Tertiary sedimentary rocks	**0.78**	**1.28**	-0.69	-1.08	**0.11**	-2.85	-2.69	**0.44**	-2.65	-3.3
Cretaceous Mesaverde Fm	-0.36	-1.15	-1.16	-1.8	**0**	-3.34	-3.75	-1.83	-2.39	-3.64
Cretaceous Mancos Shale	**0.23**	**0.04**	-0.95	-1.53	**0.04**	-2.37	-2.93	-1.18	-2.4	-3.3
Mesozoic sedimentary rocks	**0.35**	**0.02**	-1.67	-2.27	**0.01**	-2.89	-2.65	-2.74	-2.04	-2.73
Paleozoic sedimentary rocks	**0.51**	**0.45**	-0.89	-2.18	-0.24	-2.47	-3.17	-1.92	-3.72	-3.25
Tertiary and Proterozoic intrusive and metamorphic rocks	-1.34	-3.28	-1.93	-3.46	**0.14**	-3.68	-2.87	-4.29	-1.52	-3.38

Bold type indicates satuartion or supersaturation of the waters with respect to mineral phase

Comparison of the Waters from the Ten Rock Compositional Types with Mineralized Rocks

No significant mineralization or mining has taken place in the watersheds sampled in the three National Forests. Significant mineralization has taken place in other watersheds in the three National Forests, particularly the upper Uncompahgre and San Miguel Rivers and around the Crested Butte area. These areas have been affected by the mining and the determination of natural baselines for these areas can not be done directly. Contamination from mining has altered the natural background of waters in watersheds where mining has taken place. Redcloud Peak area near Lake City is administered by the Bureau of Land Management (BLM) and is adjacent to the Gunnison and Uncompahgre National Forests. The area contains significant mineralization, but no significant mining has taken place. Water samples of streams from the Redcloud Peak area were collected in a prior study (Miller and McHugh, 1998). The water chemistry of this mineralized area can be compared to the waters from the ten rock compositional types in the GMUG area in order to evaluate the effects of significant mineralization on water chemistry. The waters from the Redcloud Peak area approximate, in a qualitative manner only, the natural baselines of waters from watersheds within the mined areas in the GMUG areas. This comparison is only to show trends of what the effect of mineralization is on water chemistry in watersheds containing significantly mineralized rocks, and not to determine the pre-mining natural geochemical baselines of waters from mined watersheds in the GMUG area. The Redcloud Peak area is located within the Lake City caldera. Samples of water were collected in July, 1994 from 19 headwater streams in watersheds underlain by the Sunshine Peak silicic alkalic rhyolite tuff. The tuff unit is a multiple-flow more than 1 km thick, densely welded and propylitically altered about 22.5 m.y. ago (Lipman, 1976). The chemical analyses of the 19 stream waters are shown in the appendix 2. A summary of the ranges and means of selected species in stream waters from the Redcloud Peak area is shown in Table 19.

The relief of the Redcloud Peak area is high and the dominant vegetation is alpine tundra and subalpine forest. Annual precipitation ranges from 25 to 40 inches. The 19 sites are mostly Ca^{2+}-SO_4^{2-} type waters, which is in contrast to the GMUG waters which are mostly Ca^{2+}- HCO_3^- type waters. The waters are acidic to slightly alkaline in pH with moderately low conductivity values. Natural acid-drainage waters are present in the upper portions of several of the watersheds. Abundant Al hydroxides precipitate along several streams and at junctions with tributaries. Fe hydroxides are also precipitating, but are not as abundant as the Al hydroxides. The mineralized rocks contain disseminated pyrite and the oxidation and dissolution of the pyrite release acidity and sulfate to the waters (see Miller and others (1998) for details on these

Table 19. Nineteen waters from areas underlain by the mineralized Sunshine Peak rhyolitic ash-flow tuff, Lake City caldera.

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	44	320	110
TDS	31.3	166.7	66.4
pH	3.58	7.6	6.09
Ca	6.3	33	12
Mg	0.5	4.5	1.6
Na	0.4	4.4	1
K	0.3	4.5	1
SiO_2	3	29	8.4
Alkalinity	<1	94	3.9
SO_4	6.9	106	30
Cl	<0.1	0.18	0.12
F	<0.5	0.96	0.17
Al	<100	4400	420
Fe	<10	450	30
Mn	<10	2000	40
Cu	<1	6	1.2
Zn	<5	280	11
Mo	<1	9	1
As	<1	1	<1
U	<0.1	8.1	0.66
Li	<1	21	3.7
Ba	0.9	32	7.7
Sr	29	320	72
Sc	2	8.9	5.1
Rb	0.8	21	3.3
Y	<0.1	13	0.43
La	<0.1	66	0.58

[1]TDS, Ca, Mg, Na, K, SiO_2, SO_4, Cl, and F in mg/l, alkalinity in mg/l HCO_3, conductivity in uS/cm, remaining elements in ug/l.
[2]All variables are geometric means except for pH

processes for natural acid drainage in this area). Al is mobilized because of the low pH values. Values for pH range from 3.58 to 7.6 with a mean of 6.09 (Table 19). The mean pH value of waters from areas underlain by the mineralized Sunshine Peak Tuff is much lower than waters from areas underlain by the ten predominantly unmineralized rock types from the GMUG area (Table 20). Because of the low pH values, most of the alkalinity generated in the Redcloud Peak area is consumed by the acidity released by the weathering of pyrite. Alkalinity values range from 0 to 94 mg/l as HCO_3^-, with a mean of 3.9 mg/l. This is much lower than mean alkalinity values of waters from the GMUG area. If mean alkalinity values are normalized in a manner similar to that done for the waters from the GMUG area, the mean normalized alkalinity is also much lower than waters from the GMUG area (Table 21).

Values for conductivity for waters from the Redcloud Peak area range from 44 to 320 µS/cm, with a mean of 110 µS/cm, which is moderately low and a reflection of the large input of runoff from melting snow, the short time of contact of waters with rocks, and the poor groundwater reservoir of this mountainous headwater area. Concentrations of Cl are very low with a mean of 0.12 mg/l, again suggesting a large input of runoff from melting snow. Mean TDS values of waters from the Sunshine Peak is 66.4 mg/l (Table 20), which is lower than 8 of the rock compositional types from the GMUG area. If TDS is normalized in a manner similar to that done for the waters from the GMUG area, the mean normalized TDS is second only to waters from areas underlain by Paleozoic sedimentary rocks (552 vs. 715) (Table 21). Therefore the potential release of TDS from areas underlain by the mineralized Sunshine Tuff is higher than nine of the ten areas of predominantly unmineralized rocks in the sampled watersheds in the GMUG area.

Sulfate concentrations in waters from areas underlain by the Sunshine Peak Tuff range from 6.9 to 106 mg/l with a mean of 30 mg/l (Table 19). This mean value is much higher than the means of waters from the sampled GMUG watersheds, mainly because larger amounts of pyrite, which is the likely source of the sulfate, are present in the Sunshine Peak Tuff than sampled watersheds in the GMUG area. If the sulfate concentrations are normalized by dividing by Cl concentrations to reduce the effect of time of contact of water and rock and evaporation, the differences are even more striking (Table 21).

Mean value of F of waters from areas underlain by the Sunshine Peak Tuff is 0.17 mg/l (Table 19). Only waters from areas underlain by Tertiary intrusive and Proterozoic rocks in the GMUG areas have a higher mean F concentration of 0.21 mg/l. If the F concentration is normalized by dividing by the Cl concentration, the mean value of waters from areas underlain by the Sunshine Peak Tuff area is 1.41 compared to 0.54 from the Tertiary intrusive and Proterozoic rocks areas (Table 21). This suggests that the F content in the Sunshine Peak Tuff is higher than rocks in the GMUG study areas, including the Tertiary intrusive and Proterozoic

Table 20. Comparison of the geochemistry of waters from watersheds underlain by relatively unmineralized rocks in the GMU areas to wates from mineralized Sunshine Peak tuff, Redcloud Peak area.

Rock composition type	Number	Water Type	Temp °C	pH	Conductivity uS/cm	TDS mg/l	Ca mg/l
GMUG area							
Tertiary basalt flows and associated rocks	4	Ca, HCO_3	12.2	7.41	63	39.3	5.4
Tertiary felsic ash-flow tuff	5	Ca, HCO_3	9.9	7.43	100	74.5	11
Tertiary quartz latitic lava and breccia	4	Ca, HCO_3	7.0	7.48	124	93	12.6
Tertiary andesitic lava, breccia, tuff	9	Ca, HCO_3	12.6	7.94	151	109.4	16
Tertiary sedimentary rocks	7	Ca, HCO_3	15.9	8.50	365	196	39
Cretaceous Mesaverde Formation	8	Ca, HCO_3	14.4	8.31	126	69.5	13
Cretaceous Mancos Shale	11	Ca, HCO_3	14.4	8.24	294	133.8	35
Mesozoic sedimentary rocks	5	Ca, HCO_3	8.8	7.94	413	200.3	59
Paleozoic sedimentary rocks	15	Ca, HCO_3	9.4	8.30	356	174	52.6
Tertiary and Proterozoic intrusive and meta	8	Ca, HCO_3	7.3	7.82	83	50.9	8
Redcloud Peak Area							
Sunshine Peak Tuff	19	Ca, SO_4	9.7	6.09	110	66.4	12

Mg mg/l	Na mg/l	K mg/l	SiO_2 mg/l	Alkalinity mg/l	SO_4 mg/l	Cl mg/l	F mg/l	Al ug/l	Fe ug/l	Mn ug/l	Cu ug/l	Zn ug/l
2.1	1.8	0.37	14.3	28	0.65	0.29	<0.10	54	91	15	<1	0.40
1.7	4.3	1.3	29.9	46	2.7	0.88	0.10	16	65	2.9	<1	0.24
1.8	6.9	1.1	30.8	36	16.6	0.56	<0.10	55	60	2.7	0.56	0.5
2.8	7.3	1.6	34.2	67	4.1	0.65	<0.10	13	15	0.5	<1	0.21
12.0	15	1.4	17.5	191	8	1.4	0.16	12	13	4.7	<1	0.22
3	5.4	0.49	12.8	54	5.3	0.49	<0.10	12	14	2.0	<1	0.24
8.6	6.1	0.45	13.9	104	24	0.80	0.12	10	17	3.0	<1	0.22
10	5.2	1.8	10.9	205	4.7	3.4	0.12	6.7	4.6	0.68	<1	0.23
11.0	1.3	0.47	6.3	143	13.5	<0.25	<0.1	0.34	<20	0.57	<0.5	0.6
1.7	3.1	0.55	14.3	34	3.5	0.39	0.21	14	13	<0.3	<1	0.64
1.6	1	1	8.4	3.9	30	0.12	0.17	420	30	40	1.2	11

Co ug/l	Mo ug/l	Ni ug/l	Cr ug/l	As ug/l	U ug/l	Li ug/l	Be ug/l	Ba ug/l	Sc ug/l	Rb ug/l	Y ug/l	La ug/l
<0.5	<0.5	<2	<0.1	0.05	0.07	<0.5	<0.05	14	21	0.50	0.41	0.25
<0.5	<0.5	<2	<0.1	1.2	0.06	1.5	<0.05	18	34	1.2	0.10	0.024
0.06	0.41	0.4	<1	<3	0.14	3.6	<0.05	4.6	2.9	1.4	0.32	0.13
<0.5	<0.5	<2	<0.1	0.47	0.08	1.2	<0.05	4.6	39	2.3	0.07	<0.005
<0.5	1.9	<2	<0.1	1.9	1.4	7.2	<0.05	62	25	0.60	0.083	0.017
<0.5	<0.5	<2	<0.1	0.08	0.14	1.4	<0.05	18	18	0.32	0.04	0.005
<0.5	0.77	<2	<0.1	0.16	0.35	2.0	<0.05	19	20	0.20	0.06	<0.005
<0.5	<0.5	<2	<0.1	1.2	2.7	12	<0.05	286	15	2.4	0.03	0.006
0.06	0.41	1.2	2.6	<3	0.56	2.1	<0.05	88.5	0.9	0.47	0.03	<0.01
<0.5	0.83	<2	<0.1	<0.03	0.78	1.7	<0.05	8.6	19	0.35	0.17	0.036
1.1	1	1.1	<0.2	<1	0.66	3.7	0.48	7.7	5.1	3.3	0.43	0.58

Table 21. Normalized values for selected parameters and species of waters from relatively unmineralized watersheds within GMUG compared to waters from watersheds underlain by mineralized Sunshine Peak Tuff, Lake City caldera.

	Chloride	TDS	TDS/Cl	Alkalinity	Alkalinity/Cl	Sulfate	Sulfate/Cl
Tertiary basalts	0.29	39.3	133.8	28	97	0.65	2.24
Tertiary ash flow tuff	0.88	74.5	84.7	46	52	2.7	3.07
Tertiary latitic lava and breccia	0.56	93	166	36	64	16.6	30
Tertiary andesites	0.65	109.4	155.5	72	103	3.5	5
Tertiary sediments	1.4	196	144.6	191	136	8.1	5.79
Cretaceous Mesaverde Fm	0.49	69.5	141.5	54	110	5.3	10.82
Cretaceous Mancos Shale	0.8	133.8	222.2	101	168	18	30
Mesozoic sediments	3.4	200.3	58.1	205	59	4.7	1.34
Paleozoic sediments	<0.25	174	714.6	143	572	13.5	54
Tertiary and Proterozoic rocks	0.39	50.9	131.5	34	87	3.5	8.97
Sunshine Peak Tuff	0.12	66.4	552.4	3.9	33	30	252

Total dissolved solids (TDS) in mg/l, chloride, sulfate, and fluoride in mg/l, alkalinity in mg/l HCO_3^-, remaining elements in ug/l.

F	F/Cl	U	U/Cl	Li	Li/Cl
0.07	0.24	0.069	0.24	0.3	1.03
0.1	0.11	0.058	0.07	1.5	1.7
<0.1	0.125	0.14	0.25	3.6	6.4
0.07	0.1	0.092	0.13	1.3	1.86
0.16	0.11	1.4	1	7.2	5.14
0.11	0.22	0.13	0.27	1.4	2.86
0.12	0.2	0.27	0.45	1.6	2.67
0.12	0.03	2.7	0.77	12	3.43
<0.1	0.28	0.56	2.24	2.1	8.4
0.21	0.54	0.78	2	1.7	4.36
0.17	1.41	0.66	5.49	3.7	31

rocks.

Mean concentrations of Cu, Mo, and As are low in waters from areas underlain by the Sunshine Peak Tuff, which is similar to that of waters from the GMUG watersheds. Mean Zn concentration of 11 μg/l is high compared to the GMUG watersheds in which the highest mean concentration of Zn is 0.64 μg/l from the Tertiary intrusive and Proterozoic rocks (Table 20). Mean U concentration of 0.66 μg/l in waters from areas underlain by the Sunshine Peak Tuff is elevated probably because of the felsic rock type, but not as high as Mesozoic and Tertiary sedimentary rocks and Tertiary intrusive and Proterozoic rocks (Table 20). Mean concentrations of Al and Mn are higher in waters from areas underlain by the Sunshine Peak Tuff, with mean concentrations of 420 and 40 μg/l compared to the GMUG waters (Table 20). Within the GMUG area, waters from areas underlain by Tertiary basaltic rocks contained the highest mean Al concentration of 54 μg/l, nearly an order of magnitude less than waters from areas underlain by the Sunshine Peak Tuff. The weathering of the pyrite, present in the Sunshine Peak Tuff, releases acidity which mobilizes the Al in the waters. Within the GMUG area, waters from areas underlain by Tertiary sedimentary rocks contained the highest mean Mn concentration of 4.7 μg/l, nearly an order of magnitude less than waters from areas underlain by the Sunshine Peak Tuff (Table 20). Mean Fe concentration of waters from areas underlain by the Sunshine Tuff area is 30 μg/l, which is elevated in concentration compared to the GMUG watersheds, but waters from Tertiary basaltic rocks (91 μg/ll) and Tertiary ash-flow tuff (65 μg/l) contained higher mean concentration of Fe.

Summary and Conclusions

This study determines, for mountainous headwater areas, the range of baseline geochemistry of stream and spring waters that evolve within each of ten major rock compositional types present in the Gunnison, Uncompahgre, and Grand Mesa National Forests. Processes responsible for the control and mobility of elements in water were investigated. By comparing the geochemistry of the waters that evolve in each of the dominant rock compositional types, conclusions can be drawn characterizing the rock compositional types as to their acid-neutralizing capacities and potential release of TDS or chemical weathering rates for each of the different rock compositional types. For each of the three National Forests, map plots showing potential release of TDS, mean pH values, and acid-neutralizing capacities, are made for each of the ten major rock compositional types. Also, processes responsible for the control and mobility of elements in water were investigated. In addition, the geochemistry of waters from the sampled watersheds in the GMUG, which are underlain by rocks that are relatively unmineralized, are compared to waters from the Redcloud Peak area, an adjacent area administered by the BLM which has been mineralized and probably contains significant mineral deposits. The following are the most significant conclusions based on these results:

- 1. The baseline geochemistry of stream and spring waters evolving in the mountainous 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, such as 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 headwater areas in GMUG are generally Ca^{2+}- HCO_3^- type waters, with alkaline pH values, low to moderate total dissolved solids, and generally are of good chemical quality, with low concentrations of elements such as Cu, Zn, Mo, As, U, Al, Fe, and Mn. Some waters may have slightly elevated concentrations of some of these elements because of the presence of minerals such as pyrite. Dominant species present in most of 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. Chloride concentrations of most of the waters from the three National Forest are generally low, which indicates considerable snowmelt component of stream waters. These mountainous headwater areas have shallow soil zones with minimal groundwater reservoirs. Therefore, except for the Mesozoic and Tertiary sedimentary rocks, the time of contact of water with the rocks is short and evaporation processes are minimal.

- 4. TDS values, which are measures of the chemical weathering rates, indicate that waters with the highest TDS values evolves from watersheds underlain by Mesozoic and Tertiary sedimentary rocks. Waters with the lowest TDS values evolve from watersheds underlain by Tertiary basaltic rocks and Tertiary intrusives and Proterozoic rocks. If TDS values are normalized by dividing by Cl concentrations and reducing the effects of time of contact of water and rock and evaporation processes, the rocks with the highest potential release of TDS are Paleozoic sedimentary rocks followed by the Mancos Formation, Tertiary sedimentary rocks, and the Mesaverde Formation. Potential release of TDS does not take into account the amount of precipitation of an area.

- 5. Sulfate concentrations of waters from areas underlain by Paleozoic sedimentary rocks reach up to several hundred mg/l. The high concentration of sulfate is probably due to the dissolution of gypsum present in the Permian and Pennsylvanian rocks. The Evaporite Facies to the north of the Gunnison National Forest contains gypsum and intertongues with the Minturn and Lower Maroon Formations (Tweto, 1979) present in the sampled watersheds.

- 6. Alkalinity is measure of the acid-neutralizing capacity of waters to introduced acidification. Waters from Mesozoic and Tertiary sedimentary rocks have the highest mean alkalinity values. The waters with the lowest mean alkalinity values and the most susceptible to introduced acidity are from the top of Grand Mesa, which is underlain by basaltic rocks, and areas underlain by Tertiary intrusive and Proterozoic rocks. When alkalinity is normalized by dividing by Cl to reduce the effects of evaporation and time of contact of water and rocks, the waters with the highest mean normalized alkalinity are from watersheds underlain by Paleozoic sedimentary rocks followed by the Mancos Shale and Tertiary sedimentary rocks. The higher normalized alkalinity values of waters from watersheds underlain by these rocks are probably because of the presents of carbonate rocks and local calcareous zones present within these units. The watersheds underlain by these rock types have the greatest acid-neutralizing capacities and are the most resistant to introduced acidification from processes such as acid-mine drainage or dry fallout from coal-burning power plants. The waters with the lowest mean normalized alkalinity values are watersheds underlain by Tertiary ash-flow tuff and Tertiary intrusive and Proterozoic rocks, which are the most susceptible to introduced acidification.

- 7. The Tertiary sedimentary rocks contain oil shales which outcrop in some of the sampled watersheds. These rocks contain pyrite, generally with elevated metals. Sulfate is present in waters, up to 25 mg/l, from these watersheds, which probably indicates some weathering of pyrite, but enough calcareous material is present to generate alkalinity and consume the generated acidity. The higher pH values ensure that trace metals present as cations will form hydroxides or are adsorbed, so that their concentrations remain low. Arsenic, which is present as an anionic specie, is slightly elevated (up to 5.8 μg/l), but overall, there is only slight impact of the oil shale on the chemical water quality in these mountainous headwater areas.

- 8. The Mesaverde Formation contains extensive coal deposits which contain pyrite. Sulfate is present in waters from these watersheds (up to 19 mg/l), probably from the weathering of pyrite, but pH values are alkaline, indicating any generated acidity is being buffered by the alkalinity. The mean alkalinity value is moderately low at 54 mg/l as HCO_3^-, probably because of the acidity generated from weathering pyrite consumes some of the alkalinity. In addition, less calcareous material is probably present in the Mesaverde Formation to contribute alkalinity, compared to the other sedimentary rock units in the GMUG area. Overall, the chemical quality of the water from areas underlain by the Mesaverde Formation is good, but the unit is more susceptible to introduced acidification than the other sedimentary rock units in GMUG.

- 9. The Mancos Shale is marine in origin and contains black shale and associated pyrite and elevated trace metal values. Locally, calcareous-rich zones are present and high alkalinity is generated in waters from areas underlain by these rocks. The high alkalinity buffers any acidity generated by the oxidizing pyrite and reduces the mobility of trace metal cations because of the higher pH values. Se, present in the Mancos Shale, is known to reach elevated concentrations downstream from the headwater areas. Se concentrations in water are low (mean Se <0.2 µg/l) in these sampled mountainous headwater watersheds underlain by the Mancos Shale. The high Se concentrations in waters in lower, more arid areas underlain by the Mancos Formation outside of the GMUG area are probably concentrated by evaporation effects. The waters from these mountainous headwater areas are well buffered and good in overall chemical quality.

- 10. The Mesozoic sedimentary rocks contain uranium concentrations which have been mined adjacent to the GMUG area, along the western flank of the Uncompahgre plateau. Waters from these rocks contain only slightly elevated concentrations of uranium (up to 5.8 µg/l) and represent no problem to water quality.

- 11. Cattle are heavily grazed in portions of the GMUG area. The cattle tend to concentrate in wetlands of watersheds where their hoofs muddy and disturb the wetland surface. This physical disturbance, along with the cattle wastes, decrease the oxygen content of the water and cause more reducing conditions. One impact on water quality appears to be the increased mobility of Fe due to the more reducing conditions. But overall, the chemical quality of the waters is not significantly impacted.

The unique geochemical baselines from the ten rock compositional types demonstrates the importance of rock composition in determining the types of waters that are evolving in these mountainous headwater areas. These geochemical baselines provide a range of values that approximate the natural background geochemistry of the stream and spring waters in these watersheds for each of the ten major rock composition types. 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 in the future.

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Appendix 1. Chemical analyses of stream and spring waters from watersheds underlain by the ten dominant rock compositional types in the Gunnison, Grand Mesa, and Uncompahgre National Forests

Sample No.	Latitude			Longitude			Dominant Rock Type
	Deg.	Min.	Sec.	Deg.	Min.	Sec.	
					Tertiary basalt		
G14	39	1	58	108	10	34	basaltic flows, tuff, breccia, cong
G15	39	0	34	108	11	29	basaltic flows, tuff, breccia, cong
G16	39	0	3	108	10	36	basaltic flows, tuff, breccia, cong
G17	38	0	7	108	9	41	basaltic flows, tuff, breccia, cong
					Tertiary ash flow tuff		
G45	38	12	6	106	50	53	ash flow tuff, felsic
G46	38	10	20	106	51	15	ash flow tuff, felsic
G56	38	8	29	106	48	23	ash flow tuff, felsic
G57	38	4	56	106	50	2	ash flow tuff, felsic
G58	38	6	12	106	49	30	ash flow tuff, felsic
					Tertiary quartz latite		
C12	38	0	31	107	2	13	quartz latitic lavas and breccias
C13	38	0	38	107	2	23	quartz latitic lavas and breccias
C14	38	1	15	107	2	18	quartz latitic lavas and breccias
C15	38	1	20	107	2	23	quartz latitic lavas and breccias
					Tertiary andesite		
G47	38	38	49	106?	19	17	andesitic lava, breccia, tuff, cong
G48	38	36	23	107	19	58	andesitic lava, breccia, tuff, cong
G49	38	35	11	107	20	14	andesitic lava, breccia, tuff, cong
G50	38	34	39	107	19	59	andesitic lava, breccia, tuff, cong
G51	38	34	25	107	20	1	andesitic lava, breccia, tuff, cong
G52	38	33	35	107	19	43	andesitic lava, breccia, tuff, cong
G54	38	32	45	107	19	19	andesitic lava, breccia, tuff, cong
G55	38	30	42	107	18	53	andesitic lava, breccia, tuff, cong

Tertiary sedimentary rock							
G01	39	17	1	107	34	50	claystone, carb. sh, lignite
G02	39	14	46	107	41	1	claystone, carb. sh, lignite
G03	39	20	26	107	50	33	shale, sandstone, marlstone, oil shale
G04	39	20	19	107	50	6	shale, sandstone, marlstone, oil shale
G05	39	19	12	107	57	10	shale, oil shale, siltstone, sandstone, marl
G06	39	9	17	107	55	5	oil shale, siltstone, sandstone, marl
G07	39	12	18	107	48	46	shale, sandstone, marlstone, oil shale
Cretaceous Mesaverde Formation							
G32	38	48	45	107	18	45	sandstone, shale, coal
G33	38	48	49	107	18	44	sandstone, shale, coal
G34	38	48	43	108	18	20	sandstone, shale, coal
G35	38	50	37	107	19	7	sandstone, shale, coal
G36	38	50	36	107	19	8	sandstone, shale, coal
G37	38	52	38	107	20	4	sandstone, shale, coal
G38	38	55	17	107	20	7	sandstone, shale, coal
G39	38	55	44	107	20	18	sandstone, shale, coal
Cretaceous Mancos Shale							
G19	38	48	17	107	33	29	marine shale
G20	38	48	8	107	33	56	marine shale
G24	37	55	41	108	12	20	marine shale
G25	37	53	31	108	12	0	marine shale
G26	37	53	17	108	11	52	marine shale
G27	37	54	8	108	14	0	marine shale
G28	37	54	32	108	10	45	marine shale
G29	37	54	10	108	10	30	marine shale
G30	37	54	3	108	9	31	marine shale
G31	37	53	29	108	7	0	marine shale

Mesozoic sedimentary rock							
G09	38	44	41	108	32	59	sandstone, siltstone, shale, limestone, conglomerate
G10	38	44	48	108	33	23	sandstone, siltstone, shale, limestone, conglomerate
G11	38	40	59	108	41	25	sandstone, sandy shale, mudstone, limestone
G12	38	38	8	108	41	22	sandstone, mudstone, limestone
G13	38	35	25	108	38	56	sandstone, mudstone, limestone
Paleozoic sedimentary rock							
C01	38	49	31	106	50	54	carbonate, quartzite
C02	38	50	44	106	49	13	sandstone, grit, conglomerate, shale, limestone
C03	38	51	32	106	48	19	andstone, cong, mudstone, shale, grit, limestone, shal
C04	38	52	17	106	47	52	sandstone, conglomerate, mudstone
C05	38	53	5	106	47	25	sandstone, conglomerate, mudstone
C06	38	53	38	106	46	55	sandstone, conglomerate, mudstone
C07	38	57	55	106	46	11	sandstone, grit, cong, shale, carbonate
C08	38	57	37	106	46	13	sandstone, grit, cong, shale, carbonate
C09	38	56	58	106	46	18	sandstone, grit, cong, shale, carbonate
C10	38	55	50	106	46	10	sandstone, conglomerate, mudstone
C11	38	54	37	106	46	56	sandstone, conglomerate, mudstone
C16	38	51	23	106	42	42	sandstone, grit, cong, shale, carbonate, mudstone
C17	38	49	54	106	43	10	sandstone, grit, cong, shale, carbonate, mudstone
C18	38	49	32	106	43	42	sandstone, grit, cong, shale, carbonate, mudstone
C19	38	49	10	106	44	17	carbonate, sandstone, quartzite, grit, cong, shale
Tertiary and Proterozoic rock							
G21	38	26	31	106	21	47	granite, quartz monzonite, granodiorite
G22	38	31	46	106	24	19	granite , intermediate to felsic intrusive rock
G23	38	31	57	106	24	9	granite , intermediate to felsic intrusive rock
G40	38	34	10	106	33	35	felsic and hornblende gneiss
G41	38	34	46	106	32	32	granite, quartz monzonite, granodiorite
G42	38	35	6	106	32	18	granite, quartz monzonite, granodiorite
G43	38	37	36	106	25	19	felsic intrusive rock
G44	38	37	42	106	24	22	felsic intrusive rock

Water Type	Flow	Comments	Temperature	pH	Conductivity	TDS
			deg.C		µS	mg/L
		Tertiary basalt				
unnamed stream	2 pt/min	nearly dry	13.6	7.09	59	32
Coal Ck	2 qt/sec	some cows	13.1	7.37	66	40
unnamed stream	2-3 cfs	yell. ting, from wetlands	9.5	7.67	66	46
unnamed stream	2-4 gal/sec	from wetlands, good sample	12.7	7.49	62	41
		Tertiary ash flow tuff				
spring	1-2 pt/sec	clear, drift - pH	8.7	7.40	139	106
Blue Ck	1-2 gal/sec	v. hard to filter, wetlands, sl. sed.	13.1	8.02	132	99
spring	½ -1 pt/sec	steel pipe, clear	6	6.89	117	84
Perfecto Ck	½ -2 cfs	sl yell bn color, mod hard to filter, old cattle signs, + drift	10.6	7.37	57	49
Pauline Ck	5-7 cfs	sl yell color, hard to filter	10.9	7.46	81	53
		Tertiary quartz latite				
Mineral Creek	100 gal/sec	nearly clear, some sediments in water, hard to filter	7.4	7.4	136	75
small stream	0.25 gal/sec	sediments, hard to filter, rain	7	7.35	108	80
small stream	4gal/sec	silt, hard to filter, rain	5.7	7.4	140	78
small stream	4 gal/sec	silty from raising stream, rain	7.7	7.75	116	69
		Tertiary andesite				
W. Soap Ck	2-4 cfs	clear	12.4	7.49	104	101
Lion Gulch	1 pt/sec	clear	12.3	8.20	242	133
unnamed stream	1 pt/sec	flow intermid. in bed	16.2	8.53	185	88
unnamed stream	1 gal/sec	clear	11.8	7.93	160	121
unnamed stream	1-2 pt/sec	clear but hard to filter	10.9	7.97	144	100
unnamed stream	2 pt/sec	clear	12.4	8.06	170	109
Oregon Gulch	5-10 gal/sec	clear, + drift	11.4	7.90	142	113
Chance Gulch	1 gal/sec	sl hard to filter, + drift, sl orange color	13.5	7.86	150	117

Tertiary sedimentary rock						
Hightower Ck?	1-2 qt/sec	hard to filter, cattle	21.6	8.46	467	250
unnamed stream	2-4 pt/sec	sl. sed, cattle	23.5	8.69	652	330
W. Bush Ck	2 cfs	v. sl. sed, cattle	16	8.51	247	152
E. Bush Ck	3-4 cfs	min. cattle	14.8	8.65	365	191
Kimball Ck	½-1 gal/sec		9.1	8.47	523	274
unnamed stream	2 cfs		12.9	8.16	195	108
Park Ck	3-5 cfs	sl. hard to filter	13.4	8.55	310	157
Cretaceous Mesaverde Formation						
Coal Ck	5-10 cfs	sl. murky w/ sed.	11.1	8.36	117	65
Robenson Ck	1-2 cfs	v. sl. murky w/ sed.	15.7	8.57	268	139
spring	1 pt/sec	v. clear	11.3	8.00	257	123
Cliff Ck	10 cfs	clear	11.9	8.10	76	47
Coal Ck	10-15 cfs	mod. sed., hard to filter	13.3	8.30	124	68
Coal Ck	25 cfs	sl. murky	14	8.36	98	55
Coal Ck	25-30 cfs	mod. clear, drift +	17.7	8.26	103	57
	8-10 cfs	drift + pH	20	8.54	85	50
Cretaceous Mancos Shale						
spring	qt/sec	series of springs, cattle	11.4	7.46	219	124
springs	2-3 qt/sec	series of springs, cattle in area	9.7	8.17	401	212
unnamed stream	2 cfs	mod. hard to filter, sl. sed	13.5	8.14	345	175
W. Fk Beaver Ck	1-2 cfs	clear	13.4	8.26	294	147
E. Fk Beaver Ck	2-3 cfs	cleat	7.6	8.26	107	56
unnamed stream	1-2 gal/sec	v. clear	8.6	8.16	286	140
unnamed stream	2-4 qt/sec	drainage from wetlands, some cattle, prob. good sampl	20.2	8.22	245	129
Beaver Ck	1 gal/sec	cattle impacted, meadows	22	8.48	272	143
Spring Ck	½ -1 gal/sec	clear	16.1	8.58	338	176
McCullach Ck	2 gal/sec	clear	11.8	8.29	210	107

		Mesozoic sedmentary rock				
Big Dominquez Ck	3 cfs		13.7	8.53	299	143
spring	½ -1 pt/sec	galv. pipe coated w/ carb.	11.4	8.25	454	222
spring	1-2 gal/sec	good sample	7.2	7.74	527	248
spring	1 qt/sec	good sample	6.6	7.48	460	222
California Spring	1 qt/sec	pvc pipe	4.9	7.71	363	185
		Paleozoic sedimentary rock				
Walrod Gulch	5 gal/sec	some silt	8.6	8.33	442	213
small stream	2 gal/sec	abund. cream coatings	12.4	8.23	429	213
small stream	4 gal/sec	some silt	8.8	8.36	331	149
small stream	10 gal/sec	clear, Marron Fm	7.6	8.13	225	105
small stream	7 gal/sec	Marron Fm	7.2	8.25	252	118
small stream	7gal/sec	clear, Marron Fm, some igneous float	8.1	8.4	272	130
Upper Cement Ck	1 gal/sec	mine above, ls, qtzite, igneous	11.2	8.14	424	225
small stream	0.75 gal/sec	wet land, sh, cong float	11.5	8.17	403	201
small stream	10 gal/sec	silicious sed otc	9.4	8.44	659	387
small stream	5 gal/sec	silicious sed otc, some igneous float	7.3	8.38	491	260
small stream	8 gal/sec	clear, abund igneous float, also sed	9	8.39	300	138
small stream	10 gal/sec	sed and igneous float, pH drifting up	5.7	8.2	263	120
spring	1 gal/sec	coming from wetland, pH drifting up	10.7	7.97	452	224
small stream	2 gal/sec	clear, sed float, pH drifting up	11.5	8.47	327	160
Deadman Gulch	25 gal/sec	clear, pH drifting up	11.5	8.59	298	137
		Tertiary and Proterozoic rock				
spring	2-4 gal/min	steel pipe	7.7	6.89	74	54
unnamed stream	2 gal/sec	clear	11.2	7.63	71	47
Spring Ck	1 gal/sec	clear	9	7.79	126	77
unnamed stream	1 qt/sec	clear	12.1	8.14	97	58
unnamed stream	1 pt/sec	clear	10.3	8.18	118	67
unnamed stream	1 qt/sec	clear	10.8	8.18	123	63
Fitzpatrick Gulch	1-2 cfs	clear	6.5	8.00	47	31
Tunnel Gulch	1 cfs	clear	7.3	7.75	53	30

Ca	Mg	Na	K	SiO2	Alkalinity	SO4	Cl	F	N (nitrate)	Al	Fe	Mn
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L HCO3	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L
Tertiary basalt												
4.05	1.77	1.5	0.2	10.9	24	1.60	0.31	<0.10	<0.125	107	44	4
5.89	2.24	1.92	0.4	13.7	30	0.378	0.60	<0.10	<0.125	54	125	27
6.10	2.29	2.02	0.5	19.0	30	0.638	<0.25	<0.10	<0.125	38	151	21
5.65	2.13	1.92	0.4	14.9	30	0.453	<0.25	<0.10	<0.125	40	81	19
Tertiary ash flow tuff												
16.5	2.80	5.12	1	39.6	70	3.85	1.9	0.14	0.172	8	12	2
13.3	1.71	7.86	2	41.2	52	5.96	1.3	0.13	<0.125	32	61	22
14.4	2.03	3.7	1	32.6	54	2.13	1.1	0.11	<0.125	7	9	<0.3
5.30	0.826	3.47	1	20.8	32	1.37	0.55	<0.10	<0.125	34	255	1
8.44	1.63	3.1	0.9	19.2	34	2.07	0.37	<0.10	<0.125	17	640	32
Tertiary quartz latite												
15.7	2.58	3.67	1.17	9.49	29	27.9	<0.25	<0.1	<0.1	7.90	0.0724	21.4
8.74	0.78	13	2.19	26.1	35	10.4	1.50	<0.1	<0.1	356	0.159	2.2
14.5	2.94	7.94	0.688	12.3	44	17.1	0.56	<0.1	<0.1	58.9	0.0331	1.0
12.7	1.92	6.14	0.878	14.2	36	15.2	0.58	<0.1	<0.1	55.4	0.0338	1.1
Tertiary andesite												
19.3	3.32	7.28	2	39.4	32	14.0	0.34	<0.10	<0.125	12	14	<0.3
9.95	1.74	14.8	1	31.6	102	22.5	0.82	<0.10	<0.125	9	16	3
11.4	1.66	4.91	0.8	21.9	84	5.16	0.70	0.11	<0.125	10	9	0.6
22.2	7.72	12.4	2	34.7	80	1.88	0.70	<0.10	<0.125	16	11	<0.3
21.5	4.20	5.68	2	29.5	68	2.74	0.76	0.14	0.136	12	14	0.3
14.8	2.84	11.1	2	35.0	82	2.58	0.71	<0.10	<0.125	21	16	<0.3
16.5	3.03	5.55	2	47.4	72	1.36	0.81	0.10	<0.125	14	24	<0.3
18.9	2.33	5.54	2	48.1	78	0.757	0.99	<0.10	<0.125	14	31	4

Tertiary sedimentary rock												
62.3	11.4	20.5	4	6.5	250	14.0	8.3	0.51	<0.125	24	36	171
42.7	36.9	45.1	3	19.6	352	5.34	3.4	0.17	<0.125	11	17	6
31.4	6.61	9.31	0.7	17.2	160	7.39	0.63	0.11	<0.125	16	9	9
44.5	11.5	14.1	0.6	19.8	182	10.3	0.69	0.14	<0.125	21	7	2
56.1	12.6	32.2	0.8	26.8	242	25.4	1.3	0.21	<0.125	<3	<5	<0.3
18.2	7.84	5.21	2	26.1	92	3.36	0.75	0.07	<0.125	14	16	2
37.0	10.2	7.25	1	16.9	160	4.82	0.72	0.15	<0.125	16	26	7
Cretaceous Mesaverde Formation												
12.9	2.86	4.43	0.5	13.8	44	8.71	0.33	<0.10	<0.125	10	13	2
30.5	7.85	8.41	0.8	10.7	122	19.2	1.0	0.16	<0.125	13	18	7
23.8	8.29	13.4	0.3	13.1	112	7.81	0.99	0.11	<0.125	15	<5	2
7.67	1.31	4.25	0.4	14.5	34	1.48	0.25	<0.10	<0.125	9	25	1
13.5	3.06	4.22	0.5	11.9	52	8.46	0.40	<0.10	<0.125	12	14	2
10.6	2.16	4.39	0.4	12.8	40	4.65	0.37	<0.10	<0.125	10	13	1
10.8	2.22	4.88	0.4	12.7	42	4.81	0.49	<0.10	<0.125	9	12	2
8.83	1.67	3.8	0.6	12.6	40	1.67	0.57	<0.10	<0.125	27	30	2
Cretaceous Mancos Shale												
27.4	6.42	6.61	0.2	21.6	88	17.5	0.97	0.10	<0.125	8	15	5
50.3	13.3	12.8	0.2	27.1	162	27.2	1.9	0.14	<0.125	16	15	1
48.2	10.6	3.99	0.7	12.0	168	16.1	0.59	0.15	<0.125	8	39	29
41.9	7.64	3.46	0.5	8.6	120	25.9	0.40	0.16	<0.125	11	22	19
12.0	2.26	2.71	0.2	9.5	30	13.9	0.26	<0.10	<0.125	15	15	0.9
32.3	11.1	3.01	0.2	12.1	106	29.0	0.45	<0.10	<0.125	4	<5	<0.3
32.4	5.23	4.87	1	9.5	84	34.7	0.38	0.19	<0.125	10	14	3
33.6	8.32	6.97	0.5	15.7	144	6.06	1.0	0.13	<0.125	13	60	9
47.0	10.6	5.91	0.5	16.2	180	6.16	1.0	0.14	<0.125	10	8	0.5
22.0	7.18	2.53	0.4	9.5	58	36.5	0.31	<0.10	<0.125	12	9	0.4

Mesozoic sedmentary rock												
43.5	7.43	3.38	2	6.9	152	2.50	2.5	0.12	<0.125	7	25	4
60.6	13.5	10.3	2	16.9	214	7.94	6.1	0.13	<0.125	12	<5	0.4
83.8	10.8	3.51	1	9.1	262	5.16	5.8	0.15	0.316	4	<5	<0.3
73.1	11.3	2.02	2	7.8	246	3.17	1.6	0.15	0.153	<3	<5	2
43.6	9.14	14.9	3	19.0	172	7.05	3.5	<0.10	0.445	18	<5	<0.3
Paleozoic sedimentary rock												
55.3	20.4	5.38	1.33	6.29	180	33.5	1.69	0.2	0.2	1.96	<20	0.4
51.2	25	1.21	0.79	6.89	194	32.4	0.44	<0.1	0.2	< 0.1	<20	0.1
44.2	14.2	1.66	0.574	7.02	148	8.0	0.2	<0.1	<0.1	0.39	<20	0.4
40.6	2.94	0.945	0.201	4.88	110	0.8	0.2	<0.1	<0.1	4.32	<20	0.1
44.1	3.29	1.59	0.288	7.23	120	1.6	0.2	<0.1	<0.1	< 0.1	<20	0.2
47.2	4.17	1.73	0.496	7.27	138	1.1	0.2	<0.1	<0.1	< 0.1	<20	0.3
63.4	16.3	0.609	0.231	4.71	178	52.0	0.2	<0.1	<0.1	0.75	<20	0.3
57.4	17	0.61	0.108	4.41	165	40.4	0.2	<0.1	<0.1	< 0.1	<20	3.5
101	19.5	0.742	0.598	3.72	118	203.6	0.2	<0.1	<0.1	0.71	<20	0.2
63.7	20.1	0.773	0.723	4.86	138	102.2	0.2	<0.1	<0.1	< 0.1	<20	0.1
44.5	10.6	1.18	0.451	5.99	139	6.1	0.2	<0.1	<0.1	0.98	<20	0.3
44.3	4.83	1.49	0.603	9.60	112	3.8	0.2	0.1	<0.1	< 0.1	<20	0.8
64.3	17.6	2.07	0.626	8.62	169	47.4	0.2	0.1	<0.1	7.67	61	28.8
47	12.9	1.68	1.13	11.64	138	17.2	0.2	<0.1	<0.1	< 0.1	35	3.9
44.4	11.3	0.977	0.371	5.88	135	7.8	0.2	<0.1	<0.1	0.77	<20	3.6
Tertiary and Proterozoic rock												
5.89	1.24	5.01	0.6	22.3	28	4.09	0.90	<0.10	<0.125	47	35	<0.3
6.41	1.13	3.23	0.8	15.9	20	9.83	0.27	<0.10	<0.125	18	14	<0.3
11.8	4.09	3.59	0.6	21.3	42	14.7	0.36	<0.10	<0.125	9	10	0.5
9.38	2.86	3.03	0.7	13.2	50	3.58	0.49	0.69	<0.125	13	14	0.4
10.3	3.93	5.27	0.6	19.4	50	2.38	0.55	1.8	<0.125	25	30	<0.3
9.70	4.03	5.05	0.6	16.9	48	2.70	0.54	2.2	<0.125	17	13	<0.3
5.81	0.555	1.58	0.4	9.0	26	1.03	<0.25	<0.10	<0.125	5	<5	<0.3
7.05	0.507	1.15	0.2	6.1	26	1.56	<0.25	<0.10	<0.125	9	13	<0.3

Ba	Be	Cd	Co	Cu	Li	Ni	Sr	Ti	Zn	V	Sc	Cr	Ga
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
						Tertiary basalt							
17	<0.05	<0.5	<0.5	<1	<0.5	<2	29	4	0.4	<0.5	17	<0.1	<0.01
14	<0.05	<0.5	<0.5	<1	<0.5	<2	39	2	0.5	<0.5	21	<0.1	<0.01
10	<0.05	<0.5	<0.5	<1	<0.5	<2	38	<2	0.4	0.57	26	<0.1	<0.01
15	<0.05	<0.5	<0.5	<1	<0.5	<2	37	<2	0.3	<0.5	22	<0.1	<0.01
						Tertiary ash flow tuff							
25	<0.05	<0.5	<0.5	<1	2	<2	107	<2	0.3	<0.5	48	<0.1	<0.01
19	<0.05	<0.5	<0.5	<1	3	<2	109	<2	0.2	3.38	51	<0.1	<0.01
32	<0.05	<0.5	<0.5	<1	2	<2	79	<2	<.2	2.31	35	<0.1	<0.01
10	<0.05	<0.5	<0.5	<1	0.9	<2	47	<2	0.3	0.79	25	<0.1	<0.01
12	0.06	<0.5	<0.5	<1	0.9	<2	72	<2	0.3	1.26	22	<0.1	<0.01
						Tertiary quartz latite							
13.2	< 0.05	<0.5	0.07	0.76	1.7	0.4	171	0.5	0.6	0.8	1.9	< 1	< 0.02
3.54	0.1	<0.5	0.09	0.74	10.0	0.4	57.6	7.6	1	1.6	5.3	< 1	0.1
2.59	< 0.05	<0.5	0.04	< 0.5	3.0	0.3	163	1.9	0.5	1.0	2.5	< 1	0.02
3.81	< 0.05	<0.5	0.05	0.60	3.4	0.4	109	1.4	< 0.5	1.2	2.8	< 1	< 0.02
						Tertiary andesite							
6	<0.05	<0.5	<0.5	<1	1	<2	112	<2	<.2	0.80	26	<0.1	<0.01
1	<0.05	<0.5	<0.5	<1	1	<2	60	<2	<.2	2.07	42	<0.1	<0.01
3	<0.05	<0.5	<0.5	<1	0.8	<2	62	<2	0.2	2.63	37	<0.1	<0.01
5	<0.05	<0.5	<0.5	<1	3	<2	97	<2	0.3	2.32	41	<0.1	<0.01
9	<0.05	<0.5	<0.5	<1	1	<2	149	<2	0.4	2.92	37	<0.1	<0.01
6	<0.05	<0.5	<0.5	<1	0.9	<2	121	<2	0.3	2.69	48	<0.1	<0.01
8	<0.05	<0.5	<0.5	<1	1	<2	100	<2	<.2	2.67	54	<0.1	<0.01
8	<0.05	<0.5	<0.5	<1	2	<2	92	<2	0.2	2.67	51	<0.1	<0.01

Tertiary sedimentary rock													
208	<0.05	<0.5	<0.5	2	3	<2	348	<2	0.5	1.56	11	<0.1	<0.01
118	<0.05	<0.5	<0.5	1	25	<2	718	<2	0.3	4.18	27	<0.1	<0.01
42	<0.05	<0.5	<0.5	<1	5	<2	202	<2	<.2	3.13	25	<0.1	<0.01
36	<0.05	<0.5	<0.5	<1	9	<2	326	<2	<.2	4.40	27	<0.1	<0.01
44	<0.05	<0.5	<0.5	<1	17	<2	452	<2	<.2	5.51	35	<0.1	<0.01
32	<0.05	<0.5	<0.5	<1	1	<2	114	<2	0.2	2.10	36	<0.1	<0.01
69	<0.05	<0.5	<0.5	<1	12	<2	337	<2	0.3	1.28	24	<0.1	<0.01
Cretaceous Mesaverde Formation													
11	<0.05	<0.5	<0.5	<1	1	<2	82	<2	0.3	<0.5	19	<0.1	<0.01
49	<0.05	<0.5	<0.5	<1	5	<2	226	<2	0.3	<0.5	16	<0.1	<0.01
35	<0.05	<0.5	<0.5	<1	2	<2	364	<2	<.2	<0.5	17	<0.1	<0.01
11	<0.05	<0.5	<0.5	<1	0.7	<2	52	<2	0.2	0.71	21	<0.1	<0.01
14	<0.05	<0.5	<0.5	<1	2	<2	89	<2	0.2	<0.5	17	<0.1	<0.01
12	<0.05	<0.5	<0.5	<1	1	<2	70	<2	0.3	<0.5	19	<0.1	<0.01
14	<0.05	<0.5	<0.5	<1	1	<2	74	<2	0.2	<0.5	18	<0.1	<0.01
29	<0.05	<0.5	<0.5	<1	0.8	<2	75	<2	0.4	0.74	18	<0.1	<0.01
Cretaceous Mancos Shale													
14	<0.05	<0.5	<0.5	<1	2	<2	241	<2	0.5	0.74	28	<0.1	<0.01
35	<0.05	<0.5	<0.5	<1	2	<2	581	<2	0.2	0.73	35	<0.1	<0.01
35	<0.05	<0.5	<0.5	<1	2	<2	192	<2	0.2	<0.5	17	<0.1	<0.01
20	<0.05	<0.5	<0.5	<1	2	<2	141	<2	0.2	<0.5	14	<0.1	<0.01
7	<0.05	<0.5	<0.5	<1	0.9	<2	39	<2	<.2	<0.5	15	<0.1	0.013
5	<0.05	<0.5	<0.5	<1	<0.5	<2	190	<2	<.2	<0.5	17	<0.1	<0.01
26	<0.05	<0.5	<0.5	<1	6	<2	174	<2	0.4	<0.5	15	<0.1	<0.01
21	<0.05	<0.5	<0.5	<1	1	<2	176	<2	<.2	<0.5	23	<0.1	<0.01
29	<0.05	<0.5	<0.5	<1	2	<2	194	<2	<.2	1.71	24	<0.1	<0.01
16	<0.05	<0.5	<0.5	<1	1	<2	111	<2	<.2	<0.5	15	<0.1	<0.01

Mesozoic sedmentary rock													
257	<0.05	<0.5	<0.5	1	8	<2	161	<2	0.3	0.57	11	<0.1	<0.01
227	<0.05	<0.5	<0.5	<1	11	<2	241	<2	0.2	2.71	21	<0.1	<0.01
439	<0.05	<0.5	<0.5	<1	20	<2	192	<2	0.3	1.02	12	<0.1	<0.01
274	<0.05	<0.5	<0.5	<1	15	<2	205	<2	<.2	<0.5	12	<0.1	<0.01
274	<0.05	<0.5	<0.5	<1	11	<2	535	<2	0.3	<0.5	25	<0.1	<0.01
Paleozoic sedimentary rock													
108	< 0.05	–	0.06	0.63	14.5	1.2	142	0.7	1	1.0	0.9	3.2	< 0.02
61.3	< 0.05	–	0.05	< 0.5	4.5	1.2	129	0.6	0.5	0.8	1.0	3.4	< 0.02
72.9	< 0.05	–	0.06	< 0.5	2.6	0.9	56.2	0.1	0.5	0.9	0.9	2.7	< 0.02
99.0	< 0.05	–	0.05	< 0.5	0.6	1.0	25.5	< 0.1	< 0.5	0.9	0.7	2.2	< 0.02
169	< 0.05	–	0.05	< 0.5	1.0	1.0	47.0	< 0.1	< 0.5	1.6	1.0	2.1	< 0.02
264	< 0.05	–	0.06	< 0.5	1.6	1.1	94.5	< 0.1	0.6	1.8	0.9	2.3	< 0.02
64.0	< 0.05	–	0.07	< 0.5	1.2	1.5	123	0.8	0.9	0.9	0.8	3.2	< 0.02
55.7	< 0.05	–	0.07	< 0.5	1.5	1.4	143	0.7	0.7	0.8	0.6	2.7	< 0.02
54.6	< 0.05	–	0.10	0.72	1.8	2.3	793	3.1	0.7	0.7	0.6	2.3	< 0.02
53.5	< 0.05	–	0.06	0.52	2.0	1.6	419	1.6	0.8	0.7	0.7	2.7	< 0.02
134	< 0.05	–	0.06	< 0.5	1.6	1.1	70.0	0.1	0.6	1.3	0.8	2.6	< 0.02
84.5	< 0.05	–	0.04	< 0.5	2.3	0.9	38.0	< 0.1	< 0.5	0.9	1.1	2.1	< 0.02
73.7	< 0.05	–	0.12	< 0.5	3.5	1.6	246	1.1	4.7	0.9	1.1	3.1	< 0.02
85.3	< 0.05	–	0.06	< 0.5	3.4	1.1	133	0.2	< 0.5	0.7	1.3	2.3	< 0.02
102	< 0.05	–	0.06	< 0.5	1.2	1.0	47.5	< 0.1	< 0.5	0.7	0.7	2.1	< 0.02
Tertiary and Proterozoic rock													
5	<0.05	<0.5	<0.5	<1	6	<2	36	<2	0.6	<0.5	30	<0.1	<0.01
13	<0.05	<0.5	<0.5	<1	2	<2	48	<2	4	<0.5	22	<0.1	<0.01
9	<0.05	<0.5	<0.5	<1	2	<2	36	<2	5	<0.5	28	<0.1	<0.01
11	<0.05	<0.5	<0.5	<1	0.7	<2	36	<2	0.4	<0.5	20	<0.1	<0.01
29	<0.05	<0.5	<0.5	<1	2	<2	31	<2	0.3	0.51	26	<0.1	<0.01
20	<0.05	<0.5	<0.5	<1	1	<2	28	<2	0.2	<0.5	24	<0.1	<0.01
3	<0.05	<0.5	<0.5	1	1	<2	37	<2	0.3	0.57	13	<0.1	0.011
3	<0.05	<0.5	<0.5	<1	1	<2	45	<2	0.3	<0.5	-10	<0.1	<0.01

As	Se	Br	Rb	Y	Zr	Mo	Sn	Sb	I	Cs	La	Ce	Pr
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Tertiary basalt													
<0.03	<0.2	<3	0.294	0.31	0.282	0.53	<0.05	<0.01	<0.2	<0.002	0.262	0.563	0.076
0.7	<0.2	<3	0.350	0.44	0.431	<0.5	1.913	0.22	19.64	<0.002	0.313	0.500	0.103
<0.03	<0.2	<3	1.340	0.53	1.027	<0.5	<0.05	<0.01	2.05	<0.002	0.264	0.379	0.067
<0.03	<0.2	<3	0.438	0.38	0.277	<0.5	<0.05	<0.01	<0.2	<0.002	0.174	0.321	0.050
Tertiary ash flow tuff													
0.9	<0.2	33	0.764	0.08	0.220	<0.5	<0.05	0.09	7.82	<0.002	<0.005	<0.005	<0.002
2.2	<0.2	<3	2.248	0.08	0.843	0.60	<0.05	0.13	5.17	<0.002	0.068	0.142	<0.002
1.5	<0.2	<3	0.327	0.05	8.512	<0.5	<0.05	<0.01	3.51	<0.002	<0.005	<0.005	<0.002
0.9	<0.2	<3	3.118	0.14	0.124	<0.5	<0.05	<0.01	<0.2	<0.002	0.075	0.143	0.026
0.8	<0.2	<3	1.609	0.18	0.178	<0.5	<0.05	<0.01	2.51	<0.002	0.165	0.304	0.034
Tertiary quartz latite													
–	–	–	3.05	0.10	0.08	0.26	–	< 0.1	–	0.01	0.05	0.06	0.01
–	–	–	1.51	1.49	1.4	0.82	–	< 0.1	–	0.05	0.49	0.55	0.14
–	–	–	0.85	0.28	0.3	1.08	–	< 0.1	–	0.01	0.12	0.16	0.04
–	–	–	1.07	0.24	0.3	0.37	–	< 0.1	–	0.13	0.11	0.17	0.03
Tertiary andesite													
0.4	<0.2	<3	1.420	0.07	0.171	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
0.7	<0.2	<3	1.712	0.07	0.426	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	0.055	<0.002
0.6	<0.2	<3	2.122	0.10	0.277	<0.5	<0.05	0.07	<0.2	<0.002	<0.005	0.069	<0.002
0.6	<0.2	<3	3.165	0.11	0.153	<0.5	<0.05	0.06	<0.2	<0.002	<0.005	0.063	<0.002
1.3	<0.2	<3	2.032	0.07	0.256	0.53	<0.05	<0.01	<0.2	<0.002	<0.005	0.052	<0.002
0.8	<0.2	<3	2.759	0.06	0.374	0.59	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
0.5	<0.2	<3	3.717	0.05	0.227	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
1.0	<0.2	<3	3.705	0.05	0.449	<0.5	<0.05	<0.01	2.16	<0.002	<0.005	0.053	<0.002

Tertiary sedimentary rock													
1.3	<0.2	90	0.658	0.17	1.256	0.53	<0.05	0.17	35.69	0.002	0.072	0.128	0.050
1.4	<0.2	182	0.840	0.06	0.762	2.10	<0.05	0.26	24.76	<0.002	<0.005	0.283	0.037
2.4	<0.2	<3	0.569	0.07	0.182	3.28	<0.05	0.13	2.45	<0.002	0.051	0.108	0.002
4.1	<0.2	<3	0.490	0.06	0.685	2.51	<0.05	0.26	<0.2	<0.002	0.071	0.052	0.023
5.8	<0.2	<3	0.600	0.05	0.220	7.48	<0.05	0.29	<0.2	<0.002	<0.005	<0.005	<0.002
0.6	<0.2	<3	0.733	0.10	0.139	1.54	<0.05	0.09	<0.2	<0.002	<0.005	0.134	<0.002
1.3	<0.2	<3	0.403	0.12	0.628	0.82	<0.05	<0.01	2.27	<0.002	<0.005	0.110	<0.002
Cretaceous Mesaverde Formation													
<0.03	<0.2	<3	0.398	0.04	0.623	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
0.3	<0.2	<3	0.306	0.04	0.116	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.136	<0.03	0.241	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.350	0.03	0.485	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
2.4	<0.2	<3	0.447	0.04	<0.05	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	0.051	<0.002
<0.03	<0.2	<3	0.429	0.04	<0.05	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
0.6	<0.2	<3	0.365	0.06	0.057	0.63	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.279	0.12	0.500	<0.5	<0.05	<0.01	<0.2	<0.002	0.089	0.086	<0.002
Cretaceous Mancos Shale													
0.4	<0.2	<3	0.071	0.04	0.415	0.80	<0.05	-0.01	2.32	<0.002	<0.005	<0.005	<0.002
0.3	<0.2	<3	0.078	0.04	<0.05	0.72	<0.05	0.01	3.63	<0.002	<0.005	<0.005	<0.002
0.5	<0.2	<3	0.227	0.04	0.141	0.80	<0.05	0.07	3.85	<0.002	<0.005	<0.005	<0.002
0.4	<0.2	<3	0.249	0.09	<0.05	0.81	<0.05	0.14	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.153	0.06	0.069	<0.5	<0.05	0.06	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.052	0.03	0.070	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.653	0.13	0.064	1.35	<0.05	0.01	<0.2	<0.002	<0.005	<0.005	<0.002
0.5	<0.2	<3	0.230	0.05	0.073	1.28	<0.05	<0.01	3.24	<0.002	<0.005	<0.005	<0.002
0.3	<0.2	<3	0.238	0.05	0.055	1.74	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.163	0.06	<0.05	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002

Mesozoic sedmentary rock													
2.8	<0.2	<3	1.508	0.03	0.241	0.65	<0.05	0.01	2.67	<0.002	<0.005	<0.005	<0.002
2.0	<0.2	78	2.741	<0.03	0.083	<0.5	<0.05	<0.01	5.53	0.297	<0.005	<0.005	<0.002
1.8	2.71	51	4.048	<0.03	0.440	<0.5	<0.05	0.09	2.78	0.311	<0.005	<0.005	<0.002
0.3	<0.2	<3	3.455	<0.03	0.232	<0.5	<0.05	<0.01	<0.2	0.107	<0.005	<0.005	<0.002
0.6	<0.2	<3	1.466	0.20	<0.05	<0.5	<0.05	0.06	<0.2	0.037	0.064	<0.005	<0.002
Paleozoic sedimentary rock													
–	–	–	3.05	0.02	< 0.05	0.68	–	0.20	–	0.12	0.01	0.02	< 0.01
–	–	–	0.88	< 0.01	< 0.05	0.91	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	0.53	0.02	< 0.05	0.48	–	< 0.1	–	< 0.01	< 0.01	0.01	< 0.01
–	–	–	0.18	0.08	< 0.05	< 0.2	–	< 0.1	–	< 0.01	0.02	< 0.01	< 0.01
–	–	–	0.16	0.04	< 0.05	< 0.2	–	< 0.1	–	< 0.01	0.02	< 0.01	< 0.01
–	–	–	0.32	0.05	< 0.05	< 0.2	–	< 0.1	–	< 0.01	0.02	< 0.01	< 0.01
–	–	–	0.05	0.03	< 0.05	0.73	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	0.11	0.02	< 0.05	0.66	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	0.49	0.10	< 0.05	0.84	–	< 0.1	–	< 0.01	0.01	< 0.01	< 0.01
–	–	–	0.61	0.03	< 0.05	1.46	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	0.21	0.04	< 0.05	0.26	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	3.13	0.05	< 0.05	< 0.2	–	< 0.1	–	0.06	< 0.01	< 0.01	< 0.01
–	–	–	1.02	0.04	< 0.05	0.45	–	< 0.1	–	< 0.01	< 0.01	0.02	< 0.01
–	–	–	2.10	0.03	< 0.05	0.51	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
–	–	–	0.39	0.04	< 0.05	0.25	–	< 0.1	–	< 0.01	< 0.01	< 0.01	< 0.01
Tertiary and Proterozoic rock													
<0.03	<0.2	<3	0.121	0.77	0.571	<0.5	<0.05	<0.01	3.16	<0.002	0.571	0.384	0.160
<0.03	<0.2	<3	1.489	0.17	0.084	<0.5	<0.05	<0.01	<0.2	<0.002	0.083	0.067	0.032
<0.03	<0.2	<3	0.720	<0.03	0.175	0.72	<0.05	<0.01	<0.2	<0.002	0.003	<0.005	<0.002
<0.03	<0.2	<3	0.187	0.65	0.366	1.26	<0.05	<0.01	<0.2	<0.002	0.093	0.097	0.022
<0.03	<0.2	<3	0.247	0.37	0.110	1.40	1.475	0.13	<0.2	<0.002	0.109	0.136	0.037
<0.03	<0.2	<3	0.182	0.77	0.085	2.90	<0.05	<0.01	<0.2	<0.002	0.202	0.167	0.060
<0.03	<0.2	<3	0.336	0.03	12.503	<0.5	<0.05	<0.01	<0.2	<0.002	<0.005	<0.005	<0.002
<0.03	<0.2	<3	0.636	0.04	0.678	2.21	<0.05	0.15	<0.2	0.030	<0.005	<0.005	0.024

Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	W	Re
µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Tertiary basalt													
0.331	0.053	0.025	0.132	<0.001	0.048	<0.001	0.036	<0.001	0.027	<0.001	<0.002	<0.01	<0.001
0.425	0.063	0.037	0.105	0.014	0.088	<0.001	0.057	<0.001	0.033	<0.001	<0.002	3.775	<0.001
0.314	0.040	0.031	0.136	0.021	0.078	0.019	0.043	<0.001	0.041	<0.001	0.033	0.551	<0.001
0.335	0.053	0.017	0.060	<0.001	0.037	<0.001	0.029	<0.001	<0.001	<0.001	<0.002	0.112	<0.001
Tertiary ash flow tuff													
0.054	-0.001	<0.001	0.020	0.001	0.011	<0.001	<0.001	0.001	<0.001	<0.001	0.068	<0.01	<0.001
<0.004	-0.001	<0.001	0.026	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.013	0.077	<0.01	<0.001
<0.004	0.012	<0.001	0.027	<0.001	<0.001	<0.001	<0.001	<0.001	0.014	<0.001	0.112	<0.01	<0.001
0.143	<0.001	<0.001	0.038	<0.001	0.011	<0.001	0.011	<0.001	0.021	<0.001	<0.002	<0.01	<0.001
0.123	<0.001	<0.001	0.038	<0.001	0.022	<0.001	0.014	<0.001	0.024	<0.001	<0.002	<0.01	<0.001
Tertiary quartz latite													
0.06	0.01	0.005	0.009	< 0.005	0.02	< 0.005	0.01	< 0.005	0.01	–	–	< 0.02	–
0.67	0.13	0.03	0.19	0.03	0.17	0.04	0.16	0.02	0.17	–	–	< 0.02	–
0.14	0.02	< 0.005	0.04	0.006	0.04	0.009	0.03	< 0.005	0.03	–	–	< 0.02	–
0.17	0.03	0.006	0.04	< 0.005	0.03	0.008	0.02	< 0.005	0.02	–	–	< 0.02	–
Tertiary andesite													
0.054	<0.001	<0.001	0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.034	<0.01	<0.001
<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.027	<0.001	<0.001	<0.001	0.047	<0.01	<0.001
0.074	<0.001	<0.001	0.026	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	0.047	<0.01	<0.001
0.087	0.018	<0.001	<0.001	<0.001	<0.001	<0.001	0.030	<0.001	0.014	<0.001	0.020	<0.01	<0.001
<0.004	0.011	<0.001	0.026	<0.001	<0.001	<0.001	0.014	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	0.044	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
0.043	0.012	<0.001	0.033	<0.001	0.023	<0.001	<0.001	<0.001	0.021	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	0.039	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.030	<0.01	<0.001

Tertiary sedimentary rock													
0.138	0.028	0.153	0.054	0.041	0.040	0.027	0.038	0.026	0.045	0.035	0.217	0.175	<0.001
0.153	0.027	0.071	0.088	0.019	0.024	0.018	<0.001	0.018	0.026	0.022	0.192	0.192	0.016
0.064	<0.001	0.025	<0.001	<0.001	0.032	<0.001	0.013	<0.001	<0.001	<0.001	0.048	<0.01	<0.001
0.082	0.022	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.023	<0.001	0.026	<0.01	<0.001
0.040	0.016	0.030	0.037	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	0.062	<0.01	<0.001
0.083	0.016	0.015	<0.001	<0.001	0.025	<0.001	0.021	<0.001	<0.001	<0.001	0.054	<0.01	<0.001
0.059	<0.001	0.048	0.025	<0.001	0.025	<0.001	0.016	<0.001	0.017	<0.001	0.032	<0.01	<0.001
Cretaceous Mesaverde Formation													
0.047	<0.001	<0.001	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	<0.001	<0.001	0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
0.044	<0.001	<0.001	0.021	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	0.012	0.021	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	0.149	<0.001
<0.004	<0.001	<0.001	0.022	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.002	<0.01	<0.001
0.058	<0.001	<0.001	0.029	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
0.145	0.013	<0.001	0.016	<0.001	0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
Cretaceous Mancos Shale													
0.055	<0.001	<0.001	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	0.021	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	0.001
0.063	0.025	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
0.042	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	<0.001	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	0.014	<0.001	<0.002	<0.01	<0.001
<0.004	0.012	<0.001	0.034	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	0.026
<0.004	0.012	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
0.063	<0.001	<0.001	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	0.011
0.081	<0.001	<0.001	0.021	<0.001	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001

Mesozoic sedmentary rock													
0.052	<0.001	0.142	0.013	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.002	<0.01	0.010
<0.004	<0.001	0.109	0.025	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	<0.001
<0.004	<0.001	0.258	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	0.026
<0.004	<0.001	0.116	0.031	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.01	0.010
0.072	0.023	0.110	0.032	<0.001	0.010	<0.001	<0.001	<0.001	0.031	<0.001	<0.002	<0.01	0.019
Paleozoic sedimentary rock													
< 0.01	< 0.01	0.007	< 0.005	< 0.005	0.006	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.07	–
< 0.01	< 0.01	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.05	–
< 0.01	< 0.01	0.008	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.05	–
0.02	0.01	0.01	0.006	< 0.005	0.01	< 0.005	< 0.005	< 0.005	0.01	–	–	0.03	–
0.02	< 0.01	0.02	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
0.02	< 0.01	0.02	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.03	–
0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.03	–
< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.05	–
< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	0.02	–
0.01	< 0.01	0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
< 0.01	< 0.01	0.006	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.006	–	–	< 0.02	–
0.01	< 0.01	0.007	< 0.005	< 0.005	0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
0.01	< 0.01	0.009	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
< 0.01	< 0.01	0.008	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	–	–	< 0.02	–
Tertiary and Proterozoic rock													
0.658	0.170	0.029	0.186	0.018	0.170	0.031	0.098	<0.001	0.087	0.016	<0.002	<0.01	<0.001
0.163	0.011	0.014	0.026	<0.001	0.027	<0.001	0.027	<0.001	0.017	<0.001	<0.002	<0.01	<0.001
0.043	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.012	<0.001	<0.001	<0.001	<0.002	<0.01	0.017
0.236	0.087	<0.001	0.101	<0.001	0.072	0.015	0.027	<0.001	0.015	<0.001	0.002	<0.01	<0.001
0.209	0.027	0.015	0.081	<0.001	0.059	<0.001	0.035	<0.001	0.027	<0.001	<0.002	1.430	<0.001
0.332	0.081	<0.001	0.127	<0.001	0.088	0.014	0.054	<0.001	0.027	0.013	0.043	0.107	<0.001
<0.004	0.029	0.015	0.037	0.001	<0.001	0.011	0.021	<0.001	<0.001	0.017	0.206	0.261	<0.001
<0.004	-0.001	<0.001	0.026	<0.001	<0.001	<0.001	0.014	<0.001	<0.001	0.019	0.045	<0.01	<0.001

Tl	Pb	Bi	Th	U
µg/L	µg/L	µg/L	µg/L	µg/L
		Tertiary basalt		
<0.005	<0.1	<0.005	0.069	0.15
<0.005	1.42	<0.005	0.100	0.07
<0.005	<0.1	<0.005	0.092	0.06
<0.005	<0.1	<0.005	0.073	0.04
		Tertiary ash flow tuff		
0.054	<0.1	<0.005	0.567	0.19
0.059	1.10	<0.005	0.501	0.20
<0.005	<0.1	<0.005	0.072	0.06
<0.005	<0.1	<0.005	0.097	0.02
<0.005	<0.1	<0.005	0.130	0.01
		Tertiary quartz latite		
–	< 0.05	< 0.005	0.007	0.08
–	0.06	0.007	0.15	0.32
–	< 0.05	< 0.005	0.04	0.17
–	< 0.05	< 0.005	0.02	0.09
		Tertiary andesite		
<0.005	<0.1	<0.005	0.297	<0.001
<0.005	<0.1	<0.005	0.365	0.10
<0.005	<0.1	<0.005	0.280	0.28
<0.005	<0.1	<0.005	0.160	0.19
<0.005	<0.1	<0.005	0.176	0.24
<0.005	<0.1	<0.005	0.124	0.13
<0.005	<0.1	<0.005	0.122	0.20
<0.005	<0.1	<0.005	0.172	0.23

Tertiary sedimentary rock				
0.062	<0.1	1.028	1.517	2.29
<0.005	1.19	<0.005	0.841	8.84
<0.005	2.87	<0.005	0.301	1.22
<0.005	<0.1	<0.005	0.225	0.95
<0.005	<0.1	<0.005	0.248	1.70
<0.005	<0.1	<0.005	0.204	0.39
<0.005	<0.1	<0.005	0.183	0.68
Cretaceous Mesaverde Formation				
<0.005	<0.1	<0.005	0.0015	0.09
<0.005	<0.1	<0.005	0.023	0.27
<0.005	<0.1	<0.005	0.0015	0.51
<0.005	<0.1	<0.005	0.0015	0.08
<0.005	<0.1	<0.005	0.0015	0.12
<0.005	<0.1	<0.005	0.0015	0.08
<0.005	<0.1	<0.005	0.0015	0.09
0.054	<0.1	<0.005	0.021	0.13
Cretaceous Mancos Shale				
<0.005	<0.1	<0.005	0.040	0.35
<0.005	<0.1	<0.005	0.041	0.58
<0.005	<0.1	<0.005	0.037	0.45
<0.005	<0.1	<0.005	0.031	0.22
<0.005	<0.1	<0.005	0.062	0.12
<0.005	<0.1	<0.005	0.020	0.27
0.055	<0.1	<0.005	0.049	0.14
<0.005	<0.1	<0.005	0.021	0.34
<0.005	<0.1	<0.005	0.022	0.52
<0.005	<0.1	<0.005	0.022	0.12

Mesozoic sedmentary rock				
<0.005	<0.1	<0.005	0.094	1.43
<0.005	1.66	<0.005	0.077	2.33
<0.005	<0.1	<0.005	0.065	5.78
<0.005	<0.1	<0.005	0.079	2.12
<0.005	<0.1	<0.005	0.045	3.70
Paleozoic sedimentary rock				
–	< 0.05	0.005	0.02	0.84
–	< 0.05	< 0.005	0.007	1.22
–	< 0.05	< 0.005	0.006	0.69
–	< 0.05	< 0.005	< 0.005	0.13
–	< 0.05	< 0.005	0.005	0.26
–	< 0.05	< 0.005	< 0.005	0.49
–	< 0.05	< 0.005	0.006	1.08
–	< 0.05	< 0.005	0.006	0.76
–	< 0.05	< 0.005	0.01	0.54
–	< 0.05	< 0.005	0.01	0.70
–	< 0.05	< 0.005	0.005	0.28
–	< 0.05	< 0.005	0.005	0.70
–	< 0.05	< 0.005	0.008	0.74
–	< 0.05	< 0.005	0.006	0.61
–	< 0.05	< 0.005	< 0.005	0.48
Tertiary and Proterozoic rock				
<0.005	1.31	<0.005	0.079	7.27
<0.005	1.07	<0.005	0.046	0.62
<0.005	<0.1	<0.005	0.023	0.59
<0.005	<0.1	<0.005	0.033	0.17
<0.005	1.02	<0.005	0.071	0.98
<0.005	<0.1	<0.005	0.050	1.36
0.052	<0.1	<0.005	0.375	0.37
0.068	<0.1	<0.005	0.333	0.63

Appendix 2. Chemical analyses of 19 stream waters from watersheds underlain by the Sunshine Peak Tuff, Lake City Caldera, Redcloud Peak area.

Site	Latitude			Longitude			Type	Flow	Comments	Temp
	Deg	Min	Sec	Deg	Min	Sec				deg. C
RW02	37	58	59	107	29	7	Unnamed stream	15 gal/sec	no precipitates	8
RW10	37	56	40	107	28	42	Rock Creek	5 gal/sec	Slight staining	9
RW11	37	56	37	107	28	9	Cooper Creek	10 gal/sec	Al oxide coatings on float	10
RW12	37	56	54	107	26	19	So. Fk. Silver Creek	20 gal/sec	Al oxide coatings on float	8
RW14	37	56	56	107	26	25	Unnamed stream	1 gal/sec	Abundant recent Fe oxide precip	13
RW15	37	56	46	107	26	39	Unnamed stream	1 qt/sec	Slight Fe staining	5
RW16	37	56	28	107	27	13	Unnamed stream	3 qt/sec	Slight Fe staining	9
RW17	38	0	12	107	21	45	Alpine Gulch	18 gal/sec	Slightly murky, Fe staining	10
RW21	37	54	29	107	22	31	Unnamed stream	low	none	12
RW22	37	54	26	107	22	49	Bent Creek	mod	none	12
RW23	37	54	24	107	25	55	Unnamed stream	low	none	11
RW24	37	54	44	107	26	27	Unnamed stream	low	none	11
RW25	37	55	5	107	26	51	Unnamed stream	low	none	8
RW26	37	56	9	107	27	30	Silver Creek	mod	none	14
RW27	37	54	20	107	24	33	Unnamed stream	low	none	11
RW30	37	58	22	107	26	33	Unnamed stream	low	none	10
RW31	37	58	24	107	26	36	Upper Cooper Creek	low	none	8
RW32	37	57	53	107	27	4	Unnamed stream	low	none	6
RW33	37	57	19	107	27	50	Unnamed stream	low	none	10

pH	Cond µS/cm	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SiO2 mg/l	Alkalinity mg/l	SO4 mg/l	Cl mg/l	F mg/l	NO3 mg/l	Al mg/l
7.09	110	15	1.7	0.7	0.5	3	29	32	0.15	0.12	2	0.005
6.73	117	14	2.5	0.4	0.9	6	12	42	0.07	0.09	0.15	0.005
5.17	117	12	1.5	1	1.2	10	15	45	0.07	0.27	0.32	1.2
4.92	127	12	2	0.6	1.9	9	0.1	49	0.15	0.19	1.1	1.6
3.58	320	22	4.5	2.2	4.5	29	0.1	106	0.14	0.96	0.15	2.62
6.08	70	7.8	1.2	0.6	1.7	16	13	23	0.14	0.15	0.15	0.005
4.17	148	11	2	0.5	3.6	25	0.1	53	0.15	0.33	0.15	1.7
7	128	15	2.4	2	0.9	10	18	43	0.1	0.18	0.15	0.005
6.91	93	12	1.4	1.2	0.7	6	29	23	0.13	0.07	0.15	0.005
7	94	12	1.4	1.2	0.7	6	15	23	0.11	0.08	0.15	0.005
7.42	121	18	1.6	2.3	0.3	7	45	16	0.15	0.32	0.15	0.005
7.6	210	33	2	4.4	1.2	8	94	24	0.17	0.28	0.15	0.005
7.57	87	11	1.2	1.1	1	8	13	24	0.11	0.09	0.15	0.005
6.06	129	14	2.4	1.1	1.7	10	0.1	50	0.13	0.2	0.59	0.3
7.05	44	6.3	0.5	0.9	0.5	6	23	6.9	0.13	0.08	0.15	0.005
4.42	140	12	1.4	1.2	1.2	10	0.1	52	0.07	0.26	0.37	2.1
6.4	55	7.6	0.7	0.4	0.4	3	15	13	0.18	0.12	0.15	0.005
3.9	194	14	2.3	1.1	2.3	17	0.1	74	0.17	0.69	0.15	4.4
6.6	47	6.7	0.7	0.4	0.5	4	20	10	0.07	0.03	0.15	0.005

Mn mg/l	Fe mg/l	Cu µg/l	Zn µg/l	Co µg/l	Ni µg/l	Mo µg/l	As µg/l	U µg/l	Li µg/l	Be µg/l	Sc µg/l	Cr µg/l
0.007	0.02	0.7	2	0.7	0.7	1	0.7	0.1	3	0.15	2	0.3
0.007	0.01	0.7	7	0.7	0.7	0.7	0.7	0.07	3	0.2	3	0.15
0.5	0.04	1	90	1	2	0.7	0.7	2.6	3	1.7	2	0.15
0.52	0.007	4	110	0.7	2	0.7	0.7	6.6	5	2.9	3	0.15
2	0.45	3	280	12	7	0.7	0.7	3.4	16	6.9	7.1	0.15
0.007	0.02	0.7	10	0.7	0.7	0.7	0.7	0.2	2	0.6	4.7	0.15
1.2	0.07	3	83	4	3	0.7	0.7	3.5	8.7	4.3	6.1	0.15
0.02	0.27	0.7	5	2	1	1	0.7	0.07	2	0.15	5	0.15
0.007	0.01	0.7	2	0.7	0.7	0.7	0.7	0.3	4	0.15	4.8	0.15
0.007	0.03	0.7	2	0.7	0.7	0.7	0.7	0.2	3	0.15	4.3	0.15
0.007	0.02	0.7	2	0.7	0.7	6	0.7	2.1	11	0.15	5.4	0.2
0.007	0.02	0.7	2	0.7	0.7	9	0.7	8.1	21	0.15	5.2	0.5
0.007	0.01	0.7	2	0.7	0.7	1	0.7	0.1	2	0.15	6.9	0.15
0.26	0.03	3	100	1	2	0.7	0.7	2.6	4	2.5	6.6	0.3
0.007	0.04	0.7	2	0.7	0.7	2	0.7	0.6	4.7	0.15	7	0.2
0.67	0.07	2	130	3	2	0.7	0.7	5.2	3	3.3	8.9	0.15
0.007	0.01	0.7	2	0.7	0.7	0.7	0.7	0.07	0.7	0.15	8.2	0.15
0.53	0.04	6	93	3	0.7	0.7	1	4.6	5.7	1	8.2	0.2
0.007	0.02	0.7	2	0.7	0.7	0.7	0.7	0.07	0.7	0.15	8.1	0.15

Rb µg/l	Sr µg/l	Y µg/l	Cs µg/l	Ba µg/l	La µg/l	Ce µg/l	Pr µg/l	Nd µg/l	Sm µg/l	Eu µg/l	Gd µg/l	Dy µg/l	Yb µg/l
1.5	120	0.07	0.2	3.4	66	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
4.1	55	0.07	0.15	4.9	0.2	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
3.6	54	8.8	0.15	14	7	14	2.2	8.7	1.8	0.2	2	1.6	0.6
6.8	39	9.2	0.15	8.9	5.8	10	1.7	5.8	1.4	0.2	1.8	1.5	0.7
21	56	9.2	1.8	6.5	2.9	6.7	1	4.7	1.2	0.2	1.6	1.3	0.6
6.2	29	0.2	0.15	7.5	0.2	0.07	0.07	0.1	0.07	0.07	0.07	0.07	0.07
18	35	3.5	2.5	26	1	2.1	0.4	1.6	0.3	0.07	0.4	0.4	0.2
1.9	160	0.07	0.15	18	0.2	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1.9	140	0.07	0.15	4.3	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1.8	140	0.07	0.15	4.1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1.2	190	0.07	0.2	2.4	0.1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2.4	320	0.07	0.4	32	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2.1	38	0.07	0.15	5.1	0.2	0.1	0.07	0.1	0.07	0.07	0.07	0.07	0.07
6.6	110	4	0.2	14	2.2	3.5	0.6	2.4	0.5	0.07	0.7	0.5	0.2
1.8	39	0.1	0.7	0.9	0.07	0.1	0.07	0.07	0.07	0.07	0.07	0.07	0.07
4	49	13	0.15	14	9.8	21	2.8	10	2.2	0.2	2.4	2	0.9
0.8	42	0.07	0.15	13	0.2	0.07	0.07	0.2	0.07	0.07	0.07	0.07	0.07
9.5	44	13	1.1	7.2	4.1	13	2	9	2.1	0.3	2.9	2.2	0.8
1.1	79	0.07	0.2	14	0.07	0.1	0.07	0.07	0.07	0.07	0.07	0.07	0.07