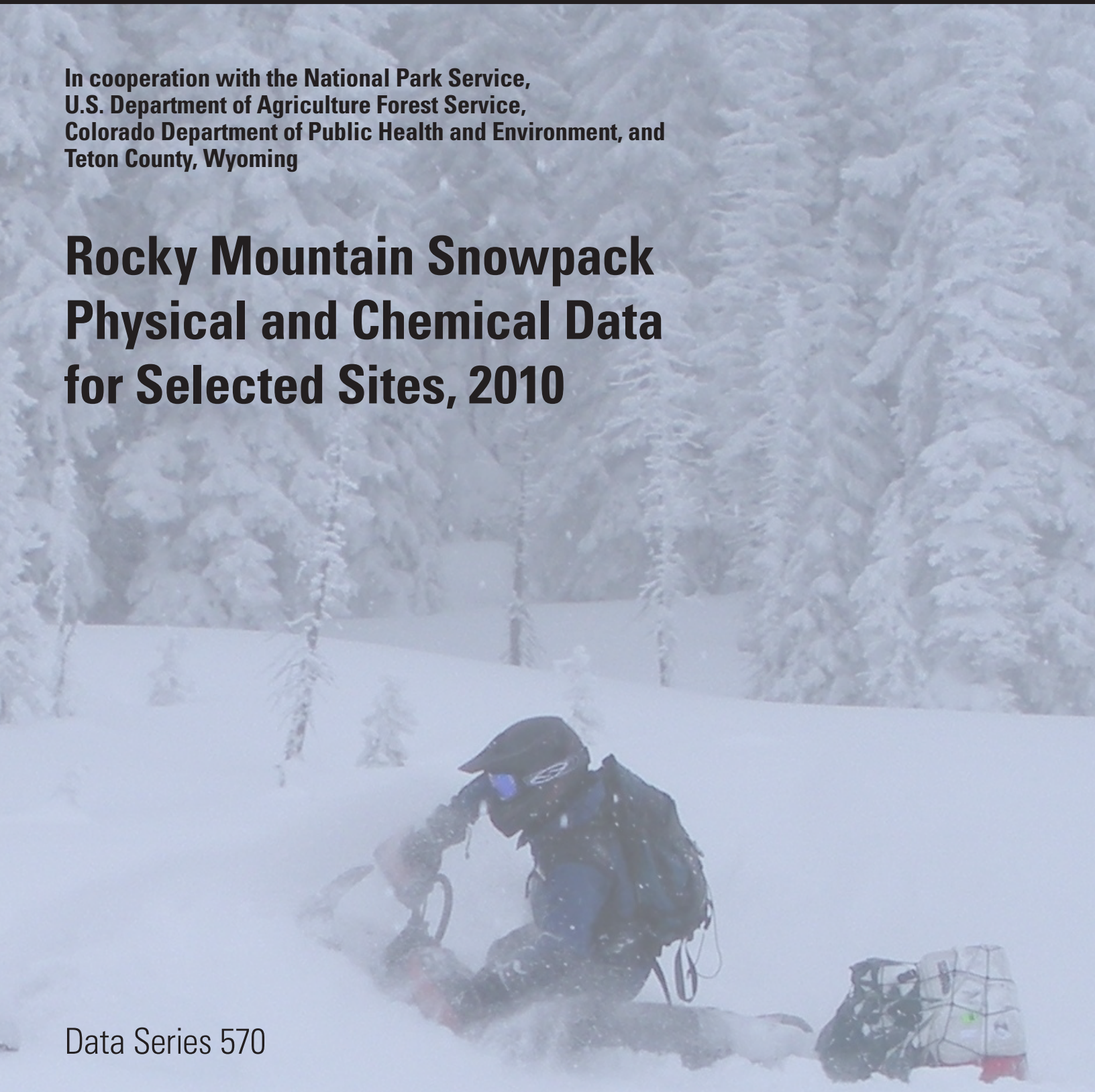
USGS
science for a changing world

In cooperation with the National Park Service,
U.S. Department of Agriculture Forest Service,
Colorado Department of Public Health and Environment, and
Teton County, Wyoming

Rocky Mountain Snowpack Physical and Chemical Data for Selected Sites, 2010



Data Series 570

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Deep snow near Buffalo Pass, Colorado.
Photograph by G.P. Ingersoll, U.S. Geological Survey.

Rocky Mountain Snowpack Physical and Chemical Data for Selected Sites, 2010

By George P. Ingersoll, M. Alisa Mast, James M. Swank, and Chelsea D. Campbell

In cooperation with the National Park Service,
U.S. Department of Agriculture Forest Service,
Colorado Department of Public Health and Environment, and
Teton County, Wyoming

Data Series 570

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

Suggested citation:
Ingersoll, G.P., Mast, M.A., Swank, J.M., and Campbell, C.D., 2011, Rocky Mountain snowpack physical and chemical data for selected sites, 2010: U.S. Geological Survey Data Series 570, 12 p.

Contents

Figure

Tables

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
	Volume	
liter (L)	33.82	ounce, fluid
	Mass	
Nanogram (ng)	$3.53x10^{-11}$	ounce

µS/cm, microsiemens per centimeter
µeq/L, microequivalents per liter

To convert microequivalents per liter (µeq/L) to milligrams per liter (mg/L) for major ions, divide microequivalents by factors indicated for each ion:

To obtain milligrams per liter for	divide by
H^+	1,000
Ca^{2+}	49.90
Mg^{2+}	82.26
K^+	25.57
Na^+	43.50
NH_4^+	55.44
SO_4^{2-}	20.83
NO_3^-	16.13
Cl^-	28.21

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Rocky Mountain Snowpack Physical and Chemical Data for Selected Sites, 2010

By George P. Ingersoll, M. Alisa Mast, James M. Swank, and Chelsea D. Campbell

Abstract

The Rocky Mountain Snowpack program established a network of snowpack-sampling sites in the Rocky Mountain region, from New Mexico to Montana, to monitor the chemical content of snow and to understand the effects of regional atmospheric deposition on freshwater systems. Scientists with the U.S. Geological Survey, in cooperation with the National Park Service; the U.S. Department of Agriculture Forest Service; the Colorado Department of Public Health and Environment; Teton County, Wyoming; and others, annually collected and analyzed snowpack samples at 48 or more sites in the Rocky Mountain region during 1993–2010. Sixty-three snowpack-sampling sites were each sampled once in 2010, and those data are presented in this report. Data include acid-neutralization capacity, specific conductance, pH, hydrogen ion concentrations, dissolved concentrations of major constituents (calcium, magnesium, sodium, potassium, ammonium, chloride, sulfate, and nitrate), dissolved organic carbon concentrations, snow-water equivalent, snow depth, total mercury concentrations, and ionic charge balance. Quality-assurance data for field and laboratory blanks and field replicates for 2010 also are included.

Introduction

The U.S. Geological Survey (USGS), in cooperation with the National Park Service; the U.S. Department of Agriculture Forest Service; the Colorado Department of Public Health and Environment; Teton County, Wyoming; and others, has been annually collecting and analyzing snowpack samples from a network of 48 or more sites in the Rocky Mountain region since 1993 (Ingersoll and others, 2009). Because snowmelt supplies most of the freshwater in mountain lakes, streams, and wetlands in the Rocky Mountain region, monitoring the chemical content of snow is critical to understanding the effects of atmospheric deposition on these systems. As part of this cooperative program, methods for measuring physical and chemical properties of seasonal snowpacks were developed for the purpose of determining atmospheric deposition in many areas of the region where no other monitoring has been done. In 2010, 63 snowpack-sampling sites (fig. 1) were each sampled once. More details about the history of the program can be found in Ingersoll and others (2002, 2009). Results of the monitoring program can be found in other reports and publications (Ingersoll and others, 2002; Mast and others, 2005).

Purpose and Scope

The purpose of this report is to publish physical and chemical data obtained in 2010 by the Rocky Mountain Snowpack program in an easily accessible document. This report contains tables listing site information, physical and chemical data, and quality-assurance data from snowpack samples collected and analyzed at 63 snowpack sites during 2010. These tables include location information and data on acid-neutralization capacity, specific conductance, pH, hydrogen ion concentrations, dissolved concentrations of major constituents (calcium, magnesium, sodium, potassium, ammonium, chloride, sulfate, and nitrate), dissolved organic carbon concentrations, snow-water equivalent (SWE), snow depth, total mercury concentrations, and ionic charge balance. These data are available with other similar snowpack data from earlier years at the USGS Web site: *http://co.water.usgs.gov/projects/RM_snowpack/html/data.html.*

Study Area

To identify regional emission signals in atmospheric deposition of nitrogen, sulfur, and mercury in the Rocky Mountain region, the snowpack-sampling sites were selected primarily along the Continental Divide in Montana, Idaho, Wyoming, Utah, Colorado, and New Mexico, in areas that are exposed to limited atmospheric emissions from local residential, commercial, or industrial activities. Snow-sampling sites were located at least 30 meters (m) away from plowed roadways to reduce contamination from vehicular traffic. There were three exceptions to this: sites on the edges of snowpack roadways in Yellowstone National Park at Old Faithful, Sylvan Lake, and West Yellowstone were intentionally selected to collect emissions from vehicular traffic. Colorado and New Mexico sites range in elevations from about 2,500 to 3,600 m; sites in Idaho, Utah, Wyoming, and Montana are typically at lower elevations, from about 1,500 to 3,300 m (table 1).

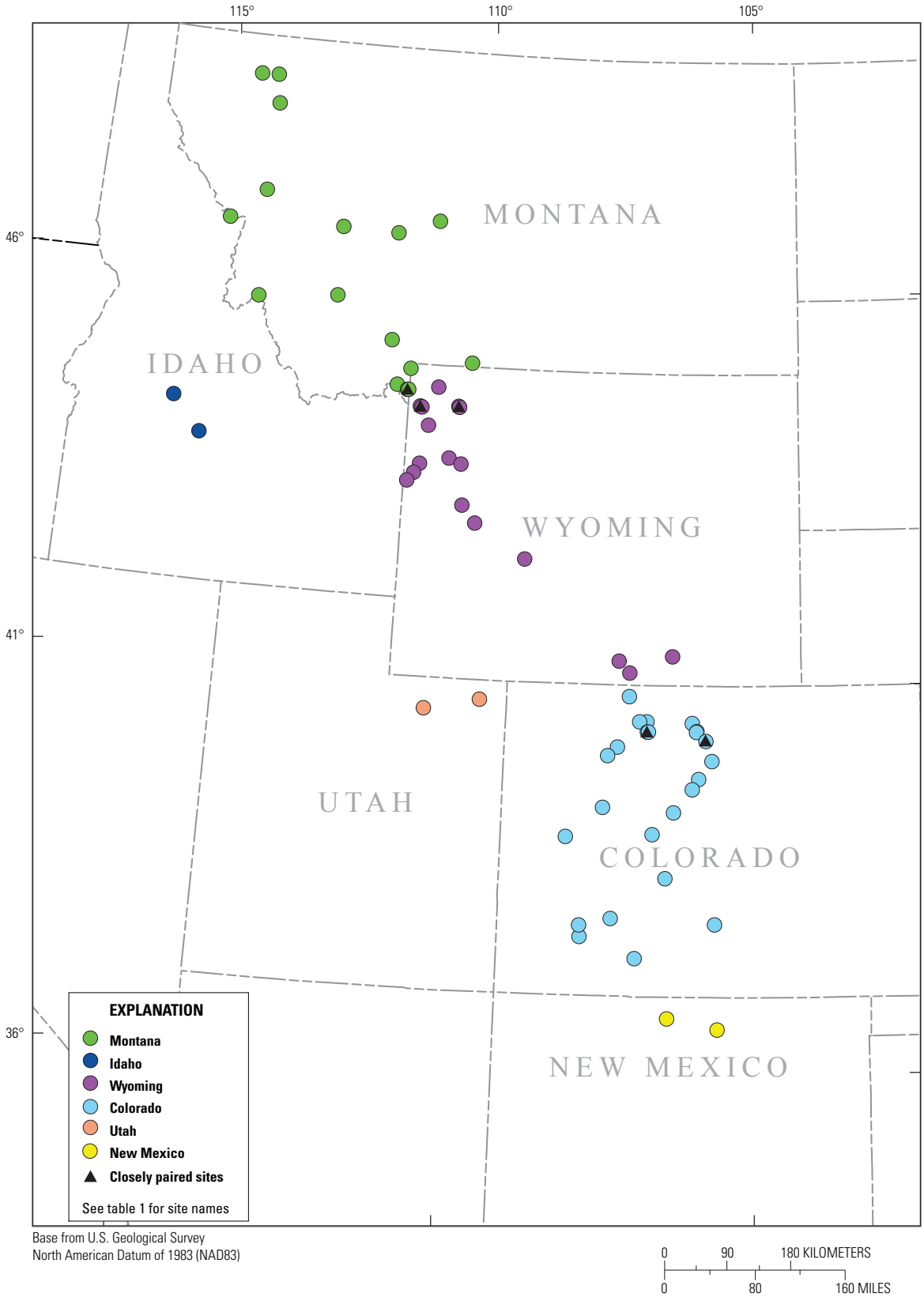


Figure 1. Study area and snowpack-sampling sites in Rocky Mountain region of the United States, 2010.

Table 1. Station identification and snow-sampling-site location information for 2010.

[dd, decimal degrees; m, meters above the North American Vertical Datum of 1988; FIPS, Federal Information Processing Standards; NADP, National Atmospheric Deposition Program].

Station identification	Site name	Latitude (dd)	Longitude (dd)	Elevation (m)	FIPS county code	FIPS state code
		Colorado				
394800105470000	Berthoud Pass, Colo.	39.81	105.78	3,466	049	8
390500106323000	Brumley, Colo.	39.09	106.54	3,231	065	8
403200106400000	Buffalo Pass, Colo.	40.55	106.68	3,139	107	8
403100105540000	Cameron Pass, Colo.	40.52	105.89	3,132	057	8
403200106470000	Dry Lake, Colo.	40.54	106.78	2,526	107	8
401200107090000	Dunkley Pass, Colo.	40.20	107.16	2,987	103	8
405100106580000	Elk River, Colo.	40.85	106.97	2,636	107	8
392200106120000	Fremont Pass, Colo.	39.36	106.22	3,440	065	8
390158107583900	Grand Mesa, Colo.	39.03	107.98	3,158	029	8
402440105484700	Lake Irene, Colo.	40.42	105.82	3,256	049	8
401722105400301	Loch Vale Forest, Colo.	40.29	105.67	3,216	069	8
401726105395801	Loch Vale Meadow, Colo.	40.29	105.67	3,215	069	8
394000105533000	Loveland Pass, Colo.	39.67	105.89	3,615	019	8
374500107420000	Molas Lake, Colo.	37.75	107.70	3,307	111	8
383100106193000	Monarch Pass, Colo.	38.51	106.33	3,223	015	8
375542105301800	Music Pass, Colo.	37.93	105.51	3,474	027	8
402355106392400	Rabbit Ears site 1, Colo.	40.40	106.66	2,986	049	8
402354106392500	Rabbit Ears site 2, Colo.	40.40	106.66	2,986	049	8
375400107430000	Red Mountain Pass, Colo.	37.89	107.71	3,396	111	8
400507107184501	Ripple Creek NADP, Colo.	40.09	107.31	2,938	045	8
375930107120000	Slumgullion Pass, Colo.	37.99	107.20	3,537	053	8
392516107223000	Sunlight Peak, Colo.	39.43	107.38	3,226	045	8
400200105340000	University Camp, Colo.	40.03	105.58	3,149	013	8
372900106470000	Wolf Creek Pass, Colo.	37.48	106.79	3,339	079	8
		Idaho				
441812115140400	Banner Summit, Idaho	44.30	115.23	2,147	015	16
435228114425200	Galena Summit, Idaho	43.87	114.71	2,686	013	16
		Montana				
483105114011200	Apgar Lookout, Mont.	48.52	114.02	1,579	035	30
483029114204200	Big Mountain, Mont.	48.51	114.35	1,959	029	30
451630111260000	Big Sky, Mont.	45.28	111.43	2,772	057	30
454113113555600	Chief Joseph Pass, Mont.	45.70	113.94	2,228	081	30
450300109570000	Daisy Pass, Mont.	45.05	109.95	2,987	067	30
463823114364100	Granite Pass, Mont.	46.64	114.61	1,994	063	30
465100110420000	Kings Hill, Mont.	46.84	110.72	2,361	013	30
444300111170000	Lionshead, Mont.	44.70	111.30	2,459	031	30
464000112300000	Mount Belmont, Mont.	46.75	112.33	2,134	049	30
480919113563600	Noisy Basin, Mont.	48.16	113.95	1,845	029	30
454730112293000	Red Mountain, Mont.	45.77	112.49	2,717	053	30

Table 1. Station identification and snow-sampling-site location information for 2010.—Continued

[dd, decimal degrees; m, meters above the North American Vertical Datum of 1988; FIPS, Federal Information Processing Standards; NADP, National Atmospheric Deposition Program].

Station identification	Site name	Latitude (dd)	Longitude (dd)	Elevation (m)	FIPS county code	FIPS state code
		Montana—Continued				
470211113594300	Snowbowl, Mont.	47.03	113.99	2,262	063	30
463900111280000	Spring Gulch, Mont.	46.65	111.47	1,826	007	30
445400111030000	Twenty-one Mile, Mont.	44.93	111.06	2,209	031	30
444000111060000	West Yellowstone, Mont.	44.66	111.09	2,035	031	30
443900111050000	West Yellowstone (in road), Mont.	44.66	111.09	2,032	031	30
		New Mexico				
364300106160000	Hopewell, N. Mex.	36.71	106.25	3,036	039	35
363429105273000	Taos Ski Valley, N. Mex.	36.57	105.45	3,320	055	35
		Utah				
404456109301800	Grizzly Ridge, Utah	40.75	109.51	2,914	047	49
403544110260200	Lake Fork, Utah	40.60	110.43	3,094	013	49
		Wyoming				
412200106140000	Brooklyn Lake, Wyo.	41.37	106.24	3,231	001	56
444300110320000	Canyon, Wyo.	44.72	110.51	2,416	029	56
411800107100000	Divide Peak, Wyo.	41.30	107.16	2,634	007	56
430000109450000	Elkhart Park, Wyo.	43.00	109.76	2,865	035	56
434900110160000	Four Mile Meadow, Wyo.	43.82	110.26	2,406	039	56
434326110465900	Garnet Canyon, Wyo.	43.71	110.75	2,174	039	56
431322109592700	Gypsum Creek, Wyo.	43.23	110.00	2,516	035	56
441300110400000	Lewis Lake Divide, Wyo.	44.20	110.66	2,363	039	56
410900106580000	Old Battle, Wyo.	41.15	106.98	3,024	007	56
442721110500300	Old Faithful fire road, Wyo.	44.46	110.83	2,246	39	56
442640110503300	Old Faithful (in road), Wyo.	44.46	110.83	2,250	39	56
433606110522200	Rendezvous Mountain, Wyo.	43.60	110.87	3,040	039	56
423420108503200	South Pass, Wyo.	42.57	108.84	2,755	013	56
442900110090000	Sylvan Lake, Wyo.	44.47	110.15	2,566	029	56
442900110090100	Sylvan Lake (in road), Wyo.	44.47	110.15	2,572	029	56
433000110590000	Teton Pass, Wyo.	43.50	110.97	2,480	039	56
434500110030000	Togwotee Pass, Wyo.	43.75	110.05	2,926	039	56

Sampling Methods and Analyses

Snowpacks were sampled annually from late February through early April according to field methods described in Ingersoll and others (2005). Snow depth was measured at all sites and SWE was measured at selected sites during the period. Snow samples from each of the 63 sites are included in this report (table 2). Analytical laboratory methods and quality-assurance procedures for analyses of major-ion and mercury concentrations are described in Turk and others (2001) and Ingersoll and others (2005). Samples were analyzed in USGS laboratories in Lakewood, Colorado; Boulder, Colorado; and Middleton, Wisconsin. Laboratory reporting levels (LRL) are based on long-term method-detection limits (LT-MDL) and are calculated as two times the LT-MDL (for details see Childress and others, 1999). The LRLs shown in tables 2–4 are 1.0 microsiemens per centimeter (µS/cm) at 25° Celsius for specific conductance, 0.4 to 3.1 microequivalents per liter (µeq/L) for major dissolved constituents and nutrients (calcium, 3.1; magnesium, 1.7; sodium, 1.0; potassium, 0.4; ammonium, 1.0; chloride, 1.0; sulfate, 0.6; nitrate, 0.4), 0.4 milligram per liter (mg/L) for dissolved organic carbon (DOC), and 0.7 nanogram per liter (ng/L) for total (whole-water) mercury. Censored values (preceded by "<") in this report reflect non-detection based on the LRL. Ammonium and nitrate concentrations are reported as NH_4^+ and NO_3^-, respectively (not as N); sulfate concentrations are reported as SO_4^{2-} (not as S). Negative acid neutralization capacity (ANC) values shown in this report reflect the absence of bicarbonate ion at the typically low pH levels, although for many samples positive ANC was detected.

Quality-assurance data for field and laboratory blanks and field replicates were collected and analyzed (tables 3 and 4). Ultra-pure (18-megohm resistance), de-ionized water was used for all blanks. Quality-assurance data for field and laboratory blanks show very little contamination; all but one of the major-ion- and mercury-blank concentrations were below LRL (the nitrate concentration in one field blank was at the LRL of 0.4 µeq/L). Additional information including interlaboratory comparisons of USGS standard reference samples can be found at *http://bqs.usgs.gov/srs*.

As a quality-control measure, the ionic charge balance of each major-ion analysis was calculated by dividing the sum of cations (hydrogen ion, calcium, magnesium, sodium, potassium, and ammonium) minus the sum of anions ([ANC greater than 0.0], chloride, nitrate, and sulfate), by the total cations and anions in solution. Censored values were not included in ionic balances. In general, ionic balances of results of chemical analyses for many samples included in this report had a positive bias, which is believed to be caused by organic acids that were not analyzed (Turk and others, 2001). This positive bias indicating an excess of cations also has been found in other precipitation work in the western United States (National Atmospheric Deposition Program, 2003, 2005).

In this report, the same criteria are used to identify the maximum acceptable ion-percent difference as applied by the National Atmospheric Deposition Program (2006). Ion-percent differences are considered suspect if they meet one of the following three criteria:

1. For total anions plus cations less than 50 µeq/L, the ionic balance exceeds plus or minus 60 percent;

2. For total anions plus cations greater than or equal to 50 µeq/L and less than 100 µeq/L, the ionic balance exceeds plus or minus 30 percent; and

3. For total anions plus cations greater than or equal to 100 µeq/L, the ionic balance exceeds plus or minus 15 percent.

No suspect ion percent differences were identified using these criteria (table 2).

To compare concentrations of selected major constituents between environmental samples and field-replicate samples, relative percent differences (RPD) were calculated. The RPD (expressed as a percentage in this report) is the absolute value of the difference of depth-integrated environmental-sample concentration (E) and the field-replicate sample concentration (FR), divided by the average of the environmental-sample concentration and the field-replicate sample concentration, then multiplied by 100: $RPD = (|E-FR|/[(E+FR)/2])\times 100$.

It is important to realize that as dilute concentrations approach detection limits, relative percent differences between environmental-sample concentrations and replicate-sample concentrations appear to be substantial, whereas absolute differences in concentrations are small. For example, the RPD for two potassium samples of 0.5 and 0.7 µeq/L would be 33.3 percent.

The median RPD values for the 10 constituents measured in this study ranged from 0 to 63.6 percent with a median of 10.5 (table 4). Mercury, potassium, and calcium showed the greatest variation in RPD (ranging up to 63.6, 57.1, and 45.5 percent, respectively), generally typical of concentrations near detection limits. However, the unusually high RPD values for the mercury samples from West Yellowstone (in road), Wyo. (63.6 percent) and the calcium samples from Buffalo Pass, Colo. (45.5) are uncommon given that the concentrations that were compared were about three to eight times the LRL. Overall, the replicate samples show good precision.

Snowpack Physical and Chemical Data

Site information, including location and elevation, is listed in table 1. Physical and chemical data are listed in table 2. Quality-assurance data for chemical analyses of field blank and field replicate snow samples are listed in tables 3 and 4.

Table 2. Selected physical and chemical data for Rocky Mountain Snowpack samples collected in 2010.

All concentrations are dissolved (filtered) except for ANC and mercury concentrations, which are total (unfiltered). [ANC, acid neutralization capacity; µeq/L, microequivalent per liter; µS/cm, microsiemens per centimeter; SC, specific conductance at 25ºC; pH values in standard units; H, hydrogen; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; SWE, snow-water equivalent; cm, centimeter; Hg, mercury; ng/L, nanogram per liter; na, not analyzed; <, below reporting level; Laboratory reporting levels are 1.0 µS/cm at 25º Celsius for specific conductance; 0.4 to 3.1 µeq/L for major dissolved constituents and nutrients (calcium, 3.1; magnesium, 1.7; sodium, 1.0; potassium, 0.4; ammonium, 1.0; chloride, 1.0; sulfate, 0.6; nitrate, 0.4); 0.4 mg/L for DOC; and 0.7 ng/L for mercury; %, percent; E, depth-integrated environmental; NADP, National Atmospheric Deposition Program]

Site name	Sample date	Sample type	ANC (µeq/L)	SC (µS/cm)	pH	H (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	Na (µeq/L)	K (µeq/L)
Apgar Lookout, Mont.	3/15/2010	E	–5.0	4.4	5.21	6.2	<3.1	<1.7	<1.0	0.5
Banner Summit, Idaho	3/11/2010	E	1.0	2.9	5.65	2.2	6.5	<1.7	5.4	1.0
Berthoud Pass, Colo.	4/11/2010	E	2.5	4.7	5.69	2.0	16.0	3.3	4.2	1.7
Big Mountain, Mont.	3/5/2010	E	–5.1	3.4	5.30	5.0	<3.1	<1.7	1.1	0.6
Big Sky, Mont.	3/10/2010	E	–2.5	3.9	5.45	3.5	5.5	<1.7	2.6	2.2
Brooklyn Lake, Wyo.	3/24/2010	E	–7.1	5.0	5.19	6.5	5.5	<1.7	1.1	0.9
Brumley, Colo.	3/23/2010	E	–8.0	4.3	5.23	5.9	5.5	<1.7	<1.0	0.6
Buffalo Pass, Colo.	4/5/2010	E	–7.3	5.4	5.22	6.0	8.5	<1.7	1.6	0.5
Cameron Pass, Colo.	3/26/2010	E	–5.7	5.5	5.23	5.9	8.5	2.5	1.6	2.3
Canyon, Wyo.	2/24/2010	E	–2.0	4.4	5.53	3.0	8.0	<1.7	6.8	0.8
Chief Joseph Pass, Mont.	3/6/2010	E	–5.5	4.2	5.29	5.1	3.5	<1.7	2.0	0.9
Daisy Pass, Mont.	3/2/2010	E	–2.4	3.6	5.44	3.6	5.0	<1.7	1.3	0.9
Divide Peak, Wyo.	3/25/2010	E	–8.9	7.0	5.08	8.3	6.5	<1.7	2.0	<0.4
Dry Lake, Colo.	3/19/2010	E	–18.7	8.6	4.78	16.6	4.0	<1.7	<1.0	<0.4
Dunkley Pass, Colo.	4/7/2010	E	5.9	5.9	5.35	4.5	17.0	3.3	1.7	1.5
Elk River, Colo.	3/19/2010	E	–9.2	5.6	5.12	7.6	7.0	<1.7	1.0	0.6
Elkhart Park, Wyo.	3/11/2010	E	–7.2	5.4	5.12	7.6	5.0	<1.7	1.3	0.5
Four Mile Meadow, Wyo.	3/17/2010	E	–6.9	4.2	5.18	6.6	<3.1	<1.7	<1.0	<0.4
Fremont Pass, Colo.	4/16/2010	E	39.7	7.5	6.40	0.4	41.4	3.3	1.3	1.7
Galena Summit, Idaho	3/11/2010	E	2.1	4.4	5.73	1.9	9.0	<1.7	13.4	0.7
Garnet Canyon, Wyo.	3/16/2010	E	–7.1	5.1	5.14	7.2	3.5	<1.7	<1.0	0.7
Grand Mesa, Colo.	3/23/2010	E	–3.3	5.2	5.28	5.2	9.0	<1.7	1.0	1.1
Granite Pass, Mont.	3/8/2010	E	–7.1	3.7	5.23	5.9	<3.1	<1.7	1.1	2.3
Grizzly Ridge, Utah	3/22/2010	E	0.2	6.6	5.39	4.1	16.5	4.1	2.7	2.5
Gypsum Creek, Wyo.	3/12/2010	E	–8.5	5.1	5.09	8.1	5.0	<1.7	<1.0	1.4
Hopewell, N. Mex.	3/26/2010	E	2.9	5.6	5.45	3.5	10.5	2.5	1.7	5.6
Kings Hill, Mont.	2/27/2010	E	–6.4	5.9	5.11	7.8	7.0	<1.7	2.1	2.9
Lake Fork, Utah	3/22/2010	E	–4.7	3.9	5.32	4.8	6.0	<1.7	1.1	1.0
Lake Irene, Colo.	4/2/2010	E	–9.1	5.6	5.09	8.1	9.0	<1.7	1.3	1.5
Lewis Lake Divide, Wyo.	2/22/2010	E	–0.8	4.3	5.54	2.9	7.0	<1.7	4.9	0.4
Lionshead, Mont.	3/1/2010	E	1.2	5.4	5.71	1.9	10.0	2.5	7.6	1.0
Loch Vale Forest, Colo.	4/14/2010	E	–3.8	5.2	5.41	3.9	13.5	3.3	1.6	2.2
Loch Vale Meadow, Colo.	4/14/2010	E	4.3	3.9	5.89	1.3	16.0	<1.7	1.2	0.5
Loveland Pass, Colo.	4/15/2010	E	47.9	7.9	6.70	0.2	47.4	4.1	2.4	0.8
Molas Lake, Colo.	3/24/2010	E	–5.7	3.7	5.30	5.0	4.5	<1.7	1.5	0.6
Monarch Pass, Colo.	3/23/2010	E	5.3	4.9	5.66	2.2	15.0	3.3	1.7	3.3
Mount Belmont, Mont.	2/26/2010	E	–8.3	7.5	5.04	9.1	8.0	3.3	1.6	3.5

Table 2. Selected physical and chemical data for Rocky Mountain Snowpack samples collected in 2010.—Continued

All concentrations are dissolved (filtered) except for ANC and mercury concentrations, which are total (unfiltered). [ANC, acid neutralization capacity; µeq/L, microequivalent per liter; µS/cm, microsiemens per centimeter; SC, specific conductance at 25ºC; pH values in standard units; H, hydrogen; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; SWE, snow-water equivalent; cm, centimeter; Hg, mercury; ng/L, nanogram per liter; na, not analyzed; <, below reporting level; Laboratory reporting levels are 1.0 µS/cm at 25º Celsius for specific conductance; 0.4 to 3.1 µeq/L for major dissolved constituents and nutrients (calcium, 3.1; magnesium, 1.7; sodium, 1.0; potassium, 0.4; ammonium, 1.0; chloride, 1.0; sulfate, 0.6; nitrate, 0.4); 0.4 mg/L for DOC; and 0.7 ng/L for mercury; %, percent; E, depth-integrated environmental; NADP, National Atmospheric Deposition Program]

Site name	NH_4 (µeq/L)	Cl (µeq/L)	SO_4 (µeq/L)	NO_3 (µeq/L)	DOC (mg/L)	SWE (cm)	Snow depth (cm)	Hg (ng/L)	Ionic balance (%)
Apgar Lookout, Mont.	6.3	<1.0	3.2	6.7	0.4	52	164	2.2	13.4
Banner Summit, Idaho	2.7	1.6	4.0	3.3	0.7	35	122	2.0	28.6
Berthoud Pass, Colo.	5.5	3.8	5.1	11.0	1.1	50	167	5.3	18.7
Big Mountain, Mont.	4.0	<1.0	2.9	4.1	0.4	65	195	6.1	21.0
Big Sky, Mont.	4.8	3.1	3.8	6.3	0.5	51	166	2.1	17.1
Brooklyn Lake, Wyo.	6.2	<1.0	5.1	7.2	0.7	73	247	2.7	24.2
Brumley, Colo.	3.5	<1.0	3.1	8.1	<0.4	33	128	2.0	15.9
Buffalo Pass, Colo.	5.5	<1.0	6.9	9.5	0.4	118	358	3.6	14.8
Cameron Pass, Colo.	6.1	1.6	5.6	9.7	0.9	38	142	4.9	22.7
Canyon, Wyo.	8.2	2.9	5.3	9.2	0.4	19	85	2.8	21.1
Chief Joseph Pass, Mont.	6.9	1.7	3.9	5.7	0.7	26	91	3.6	24.0
Daisy Pass, Mont.	6.6	<1.0	3.9	6.0	0.5	52	162	3.0	27.5
Divide Peak, Wyo.	6.0	<1.0	6.8	10.5	0.4	51	161	1.5	13.7
Dry Lake, Colo.	5.6	<1.0	8.5	16.0	<0.4	37	125	<0.7	3.3
Dunkley Pass, Colo.	5.9	1.2	5.5	9.1	0.5	51	198	2.6	21.9
Elk River, Colo.	6.1	<1.0	5.7	11.9	0.4	36	123	1.4	11.7
Elkhart Park, Wyo.	6.7	1.0	5.2	9.9	0.5	21	84	2.2	13.4
Four Mile Meadow, Wyo.	4.9	<1.0	2.1	7.2	<0.4	16	68	1.2	10.6
Fremont Pass, Colo.	4.8	1.2	4.6	9.1	1.1	28	112	6.9	-1.6
Galena Summit, Idaho	4.7	6.1	7.0	3.9	<0.4	36	148	2.8	21.6
Garnet Canyon, Wyo.	6.6	<1.0	3.6	7.7	0.7	27	86	1.5	23.0
Grand Mesa, Colo.	5.5	<1.0	5.0	8.3	0.5	42	145	3.9	24.3
Granite Pass, Mont.	2.5	<1.0	2.0	2.5	1.5	31	103	11.2	44.7
Grizzly Ridge, Utah	9.1	1.9	8.6	14.0	1.2	24	91	6.2	22.4
Gypsum Creek, Wyo.	3.3	<1.0	2.6	10.1	0.8	16	50	2.0	16.8
Hopewell, N. Mex.	9.1	1.6	6.3	9.8	1.5	45	156	9.0	23.0
Kings Hill, Mont.	7.3	1.4	5.9	7.4	2.2	37	124	5.4	29.6
Lake Fork, Utah	5.0	1.0	3.3	7.7	0.6	22	87	1.7	19.6
Lake Irene, Colo.	5.7	<1.0	4.7	9.4	0.6	47	172	2.5	29.0
Lewis Lake Divide, Wyo.	9.6	2.5	6.4	8.2	<0.4	39	136	1.6	18.3
Lionshead, Mont.	13.6	3.8	8.6	12.5	0.6	33	119	4.7	16.7
Loch Vale Forest, Colo.	8.9	1.3	7.3	12.0	1.4	80	240	7.4	23.6
Loch Vale Meadow, Colo.	6.1	<1.0	5.4	7.9	0.4	60	164	3.3	17.5
Loveland Pass, Colo.	3.2	3.8	4.2	6.7	0.5	34	117	1.3	-3.8
Molas Lake, Colo.	3.2	1.0	2.0	6.3	<0.4	45	147	1.2	22.8
Monarch Pass, Colo.	6.2	2.1	4.3	7.7	1.1	39	163	4.3	23.8
Mount Belmont, Mont.	12.0	1.7	8.5	14.6	2.6	22	77	11.0	20.2

Table 2. Selected physical and chemical data for Rocky Mountain Snowpack samples collected in 2010.—Continued

All concentrations are dissolved (filtered) except for ANC and mercury concentrations, which are total (unfiltered). [ANC, acid neutralization capacity; µeq/L, microequivalent per liter; µS/cm, microsiemens per centimeter; SC, specific conductance at 25ºC; pH values in standard units; H, hydrogen; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; SWE, snow-water equivalent; cm, centimeter; Hg, mercury; ng/L, nanogram per liter; na, not analyzed; <, below reporting level; Laboratory reporting levels are 1.0 µS/cm at 25º Celsius for specific conductance; 0.4 to 3.1 µeq/L for major dissolved constituents and nutrients (calcium, 3.1; magnesium, 1.7; sodium, 1.0; potassium, 0.4; ammonium, 1.0; chloride, 1.0; sulfate, 0.6; nitrate, 0.4); 0.4 mg/L for DOC; and 0.7 ng/L for mercury; %, percent; E, depth-integrated environmental; NADP, National Atmospheric Deposition Program]

Site name	Sample date	Sample type	ANC (µeq/L)	SC (µS/cm)	pH	H (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	Na (µeq/L)	K (µeq/L)
Music Pass, Colo.	3/25/2010	E	0.3	4.0	5.50	3.2	8.5	<1.7	1.5	0.8
Noisy Basin, Mont.	3/4/2010	E	–5.9	3.4	5.29	5.1	<3.1	<1.7	1.3	<0.4
Old Battle, Wyo.	3/23/2010	E	–6.4	5.4	5.15	7.1	7.5	<1.7	1.5	1.1
Old Faithful fire road, Wyo.	2/24/2010	E	–4.8	3.7	5.37	4.3	<3.1	<1.7	1.8	<0.4
Old Faithful (in road), Wyo.	2/24/2010	E	41.2	12.1	6.35	0.4	39.4	9.1	27.3	6.1
Rabbit Ears site 1, Colo.	3/21/2010	E	–9.3	6.4	5.04	9.1	7.5	<1.7	1.2	1.5
Rabbit Ears site 2, Colo.	3/21/2010	E	–10.0	6.7	5.04	9.1	8.5	2.5	1.3	1.0
Red Mountain, Mont.	3/9/2010	E	–5.2	4.9	5.27	5.4	7.5	2.5	3.1	2.4
Red Mountain Pass, Colo.	3/23/2010	E	2.0	3.4	5.85	1.4	14.0	<1.7	1.1	0.8
Rendezvous Mountain, Wyo.	3/17/2010	E	5.0	3.9	5.84	1.4	9.0	2.5	4.6	0.5
Ripple Creek NADP, Colo.	4/13/2010	E	13.5	4.3	6.21	0.6	22.5	3.3	1.2	0.5
Slumgullion Pass, Colo.	3/25/2010	E	11.1	3.9	6.08	0.8	19.0	2.5	1.4	1.3
Snowbowl, Mont.	3/7/2010	E	–8.2	4.1	5.17	6.8	<3.1	<1.7	1.1	1.2
South Pass, Wyo.	3/15/2010	E	–4.7	5.4	5.36	4.4	11.0	2.5	2.2	1.4
Spring Gulch, Mont.	2/26/2010	E	–4.1	4.6	5.31	4.9	6.0	<1.7	1.1	1.1
Sunlight Peak, Colo.	3/22/2010	E	–5.0	4.2	5.37	4.3	7.0	<1.7	1.2	1.5
Sylvan Lake, Wyo.	2/23/2010	E	–9.3	4.3	5.19	6.5	<3.1	<1.7	1.0	0.4
Sylvan Lake (in road), Wyo.	2/23/2010	E	–7.5	3.5	5.26	5.5	<3.1	<1.7	<1.0	<0.4
Taos Ski Valley, N. Mex.	3/27/2010	E	2.6	4.3	5.75	1.8	16.5	2.5	1.7	2.0
Teton Pass, Wyo.	3/15/2010	E	6.6	4.6	5.93	1.2	11.5	3.3	4.3	2.2
Togwotee Pass, Wyo.	3/18/2010	E	–3.7	3.2	5.44	3.6	5.0	<1.7	1.3	<0.4
Twenty-one Mile, Mont.	2/25/2010	E	–9.4	6.4	5.01	9.8	<3.1	<1.7	2.3	<0.4
University Camp, Colo.	4/9/2010	E	1.2	4.6	5.71	1.9	15.0	2.5	1.5	2.2
West Yellowstone, Mont.	2/25/2010	E	–6.6	6.1	5.14	7.2	5.0	<1.7	2.1	<0.4
West Yellowstone (in road), Mont.	2/25/2010	E	3.7	6.7	5.89	1.3	11.5	3.3	10.0	0.7
Wolf Creek Pass, Colo.	3/25/2010	E	–4.2	4.2	5.38	4.2	8.0	<1.7	1.5	0.6

Table 2. Selected physical and chemical data for Rocky Mountain Snowpack samples collected in 2010.—Continued

All concentrations are dissolved (filtered) except for ANC and mercury concentrations, which are total (unfiltered). [ANC, acid neutralization capacity; µeq/L, microequivalent per liter; µS/cm, microsiemens per centimeter; SC, specific conductance at 25ºC; pH values in standard units; H, hydrogen; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; SWE, snow-water equivalent; cm, centimeter; Hg, mercury; ng/L, nanogram per liter; na, not analyzed; <, below reporting level; Laboratory reporting levels are 1.0 µS/cm at 25º Celsius for specific conductance; 0.4 to 3.1 µeq/L for major dissolved constituents and nutrients (calcium, 3.1; magnesium, 1.7; sodium, 1.0; potassium, 0.4; ammonium, 1.0; chloride, 1.0; sulfate, 0.6; nitrate, 0.4); 0.4 mg/L for DOC; and 0.7 ng/L for mercury; %, percent; E, depth-integrated environmental; NADP, National Atmospheric Deposition Program]

Site name	NH_4 (µeq/L)	Cl (µeq/L)	SO_4 (µeq/L)	NO_3 (µeq/L)	DOC (mg/L)	SWE (cm)	Snow depth (cm)	Hg (ng/L)	Ionic balance (%)
Music Pass, Colo.	6.6	<1.0	5.1	7.5	0.5	53	194	3.5	22.7
Noisy Basin, Mont.	4.2	<1.0	3.0	4.2	0.5	72	245	2.3	18.8
Old Battle, Wyo.	6.1	<1.0	6.9	9.4	0.8	74	246	3.6	17.7
Old Faithful fire road, Wyo.	7.2	1.4	2.7	7.8	<0.4	15	65	1.2	5.9
Old Faithful (in road), Wyo.	17.5	20.8	13.6	11.0	3.2	na	16	47.9	7.2
Rabbit Ears site 1, Colo.	6.5	1.1	9.4	12.1	0.8	66	201	3.4	6.7
Rabbit Ears site 2, Colo.	6.9	1.1	9.4	12.9	0.4	63	202	3.8	11.4
Red Mountain, Mont.	6.8	2.1	5.9	7.3	1.6	37	129	5.3	28.6
Red Mountain Pass, Colo.	3.7	<1.0	3.4	7.5	<0.4	59	205	2.7	23.8
Rendezvous Mountain, Wyo.	6.3	2.0	5.1	6.6	<0.4	55	188	1.7	13.1
Ripple Creek NADP, Colo.	3.6	<1.0	3.5	7.5	<0.4	53	136	2.0	12.9
Slumgullion Pass, Colo.	2.7	1.1	2.8	5.8	0.5	33	128	6.2	14.1
Snowbowl, Mont.	4.0	<1.0	4.9	3.7	0.5	46	153	14.4	20.9
South Pass, Wyo.	8.0	1.2	8.6	11.8	0.9	23	88	5.0	15.5
Spring Gulch, Mont.	8.9	<1.0	4.3	8.9	0.6	14	58	2.7	24.8
Sunlight Peak, Colo.	4.5	<1.0	4.4	8.9	0.4	44	152	3.6	16.6
Sylvan Lake, Wyo.	6.6	<1.0	4.2	8.6	<0.4	31	119	1.2	6.3
Sylvan Lake (in road), Wyo.	4.8	<1.0	2.6	5.9	<0.4	na	76	0.8	9.9
Taos Ski Valley, N. Mex.	6.4	1.1	10.4	8.1	0.9	53	187	5.9	16.2
Teton Pass, Wyo.	9.1	3.1	5.3	9.0	0.6	37	123	12.8	13.6
Togwotee Pass, Wyo.	4.4	1.2	3.2	5.5	<0.4	46	149	1.5	18.4
Twenty-one Mile, Mont.	6.4	2.7	3.6	10.7	<0.4	19	68	0.9	4.1
University Camp, Colo.	7.9	1.1	6.9	9.8	0.8	37	143	na	23.9
West Yellowstone, Mont.	10.3	1.7	4.3	11.6	0.4	12	57	2.9	16.4
West Yellowstone (in road), Mont.	19.9	11.0	6.5	13.7	1.0	na	32	5.8	14.3
Wolf Creek Pass, Colo.	5.0	1.1	5.1	9.3	<0.4	84	273	3.4	10.8

Table 3. Quality-assurance data: selected chemical concentrations in blank samples collected in 2010.

All concentrations are dissolved (filtered) except for ANC and mercury which are total (unfiltered). [ANC, acid neutralization capacity; µeq/L, microequivalent per liter; SC, specific conductance at 25ºC; µS/cm, microsiemens per centimeter; pH values in standard units; H, hydrogen; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; Hg, mercury; ng/L, nanogram per liter; FB, field blank; LB, laboratory blank; <, below reporting limit]

Site name	Sample date	Sample type	ANC (µeq/L)	SC (µS/cm)	pH	H (µeq/L)	Ca (µeq/L)	Mg (µeq/L)	Na (µeq/L)	K (µeq/L)	NH_4 (µeq/L)	Cl (µeq/L)	SO_4 (µeq/L)	NO_3 (µeq/L)	DOC (mg/L)	Hg (ng/L)
Cameron Pass, Colo.	3/26/2010	FB	–4.0	2.1	5.41	3.9	<3.1	<1.7	<1.0	<0.4	<1.0	<1.0	<0.6	0.4	<0.4	<0.7
Laboratory blank	5/13/2010	LB	–6.7	1.5	5.47	3.4	<3.1	<1.7	<1.0	<0.4	<1.0	<1.0	<0.6	<0.4	<0.4	<0.7
Laboratory blank	5/13/2010	LB	–5.0	1.3	5.51	3.1	<3.1	<1.7	<1.0	<0.4	<1.0	<1.0	<0.6	<0.4	<0.4	<0.7

Table 4. Quality-assurance data: relative percent differences in concentrations between selected environmental and replicate samples collected in 2010.

All concentrations are dissolved (filtered) except for mercury which are total (unfiltered). [µeq/L, microequivalent per liter; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; NH_4, ammonium; Cl, chloride; SO_4, sulfate; NO_3, nitrate; DOC, dissolved organic carbon; mg/L, milligrams per liter; Hg, mercury; ng/L, nanogram per liter; E, depth-integrated environmental; <, less than; FR, field replicate; RPD, relative percent difference as: (|E-FR| / [(E+FR)/2]) × 100; --, not calculated]

Site name	Sample date	Sample type	Ca (µeq/L)	Mg (µeq/L)	Na (µeq/L)	K (µeq/L)	NH_4 (µeq/L)	Cl (µeq/L)	SO_4 (µeq/L)	NO_3 (µeq/L)	DOC (mg/L)	Hg (ng/L)
	4/5/2010	E	8.5	<1.7	1.6	0.5	5.5	1.0	6.9	9.5	0.4	3.6
Buffalo Pass, Colo.	4/5/2010	FR	13.5	2.5	1.8	0.8	7.5	1.2	9.0	11.1	0.6	3.2
		RPD	45.5	--	11.8	46.2	30.8	18.2	26.4	15.5	40.0	11.8
Galena Summit, Idaho	3/11/2010	E	9.0	<1.7	13.4	0.7	4.7	6.1	7.0	3.9	<0.4	2.8
	3/11/2010	FR	10.5	<1.7	16.3	0.8	4.6	7.4	8.3	3.9	0.5	3.5
		RPD	15.4	--	19.5	13.3	2.2	19.3	17.0	0.0	--	22.2
	3/26/2010	E	10.5	2.5	1.7	5.6	9.1	1.6	6.3	9.8	1.5	9.0
Hopewell, N. Mex.	3/26/2010	FR	10.5	2.5	1.6	4.9	8.9	1.5	6.2	9.7	1.2	7.3
		RPD	0.0	0.0	6.1	13.3	2.2	6.5	1.6	1.0	22.2	20.9
	3/22/2010	E	6.0	<1.7	1.1	1.0	5.0	1.0	3.3	7.7	0.6	1.7
Lake Fork, Utah	3/22/2010	FR	4.5	<1.7	1.0	1.8	5.0	<1.0	3.1	7.9	0.7	1.3
		RPD	28.6	--	9.5	57.1	0.0	--	6.2	2.6	15.4	26.7
	3/25/2010	E	8.5	<1.7	1.5	0.8	6.6	<1.0	5.1	7.5	0.5	3.5
Music Pass, Colo.	3/25/2010	FR	8.5	<1.7	1.5	0.8	6.1	<1.0	5.4	7.9	0.6	4.1
		RPD	0.0	--	0.0	0.0	7.9	--	5.7	5.2	18.2	15.8
West Yellowstone in road, Wyo.	2/25/2010	E	11.5	3.3	10.0	0.7	19.9	11.0	6.5	13.7	1.0	5.8
	2/25/2010	FR	11.0	3.3	11.2	0.7	20.0	11.9	6.9	13.7	0.9	3.0
		RPD	4.4	0.0	11.3	0.0	0.5	7.9	6.0	0.0	10.5	63.6
Lab reporting level (LRL)			3.1	1.7	1.0	0.4	1.0	1.0	0.6	0.4	0.4	0.7
RPD statistics	overall											
minimum	0.0		0.0	0.0	0.0	0.0	0.0	6.5	1.6	0.0	10.5	11.8
median	10.5		9.9	0.0	10.4	13.3	2.2	13.1	6.1	1.8	18.2	21.6
maximum	63.6		45.5	0.0	19.5	57.1	30.8	19.3	26.4	15.5	40.0	63.6

Acknowledgments

The authors are grateful for the cooperation of numerous individuals from many organizations including the National Park Service and the U.S. Department of Agriculture Forest Service. The authors thank many individuals for their assistance with logistical support and field work: Jeff Arnold, Nic Bencke, Gina Biere, Stan Bones, Keesha Clay, Liese Dean, Jay Dorr, Sam Duerksen, Dan Ely, Dan Fagre, Ben Glass, Mary Hektner, Andrea Holland-Sears, Nan Ingersoll, Helen Kempenich, Joe Markos, Craig McClure, Greg Miller, Rick Neam, Gary Nelson, Ted Porwoll, Don Rosenberry, John Sacklin, David Salo, Ed Snook, Mark Story, Terry Svalberg, and Matt Vandzura. Special thanks also to the following ski resorts, which provided generous logistical support: Big Mountain (Montana), Big Sky (Montana), Showdown (Montana), Snowbowl (Montana), Taos Ski Valley (New Mexico), and Teton Village (Wyoming).

References Cited

Childress, C.J.O., Foreman, W.T., Connor, B.F., and Mahoney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99–193, 19 p., *http://water.usgs.gov/owq/OFR_99-193/procedure.html#procedure*.

Ingersoll, G.P., Turk, J.T., Mast, M.A., Clow, D.W., Campbell, D.H., and Bailey, Z.C., 2002, Rocky Mountain snowpack chemistry network—History, methods, and the importance of monitoring mountain ecosystems: U.S. Geological Survey Open-File Report 01–466, 14 p., *http://pubs.usgs.gov/of/2001/ofr01-466/*.

Ingersoll, G.P., Mast, M.A., Nanus, Leora, Manthorne, D.J., Hultstrand, D.M., and Winterringer, J., 2005, Rocky Mountain snowpack chemistry at selected sites, 2003: U.S. Geological Survey Open-File Report 2005–1332, 17 p., *http://pubs.usgs.gov/of/2005/1332/*.

Ingersoll, G.P., Mast, M.A., Campbell, D.H., Clow, D.W., Nanus, L., and Turk, J.T., 2009, Rocky Mountain snowpack physical and chemical data for selected sites, 1993–2008: U.S. Geological Survey Data Series 369, 90 p., *http://pubs.usgs.gov/ds/369/*.

Mast, M.A., Campbell, D.H., and Ingersoll, G.P., 2005, Effects of emission reductions at the Hayden powerplant on precipitation, snowpack, and surface-water chemistry in the Mount Zirkel Wilderness Area, Colorado, 1995–2003: U.S. Geological Survey Scientific Investigations Report 2005–5167, 32 p., *http://pubs.usgs.gov/sir/2005/5167/*.

National Atmospheric Deposition Program (NRSP-3), 2003, Quality assurance report, National Atmospheric Deposition Program, 2001—NADP QA Report 2003–01: Champaign, Ill., National Atmospheric Deposition Program Office, Illinois State Water Survey, 194 p., *http://nadp.sws.uiuc.edu/lib/qa/qa2001.pdf*.

National Atmospheric Deposition Program (NRSP-3), 2005, 2003 annual & seasonal data summary for site CO97, part 2—Statistical summary of precipitation chemistry for valid samples: Champaign, Ill., National Atmospheric Deposition Program Office, Illinois State Water Survey, 1 p., accessed January 3, 2011, at *http://nadp.sws.uiuc.edu/ads/2003/CO97.pdf*.

National Atmospheric Deposition Program (NRSP-3), 2006, Quality assurance plan, version 2.0—Central Analytical Laboratory, 2006: Champaign, Ill., National Atmospheric Deposition Program Office, Illinois State Water Survey, 63 p., accessed January 3, 2011, at *http://nadp.sws.uiuc.edu/lib/qaplans/qapCal2006.pdf*.

Turk, J.T., Taylor, H.E., Ingersoll, G.P., Tonnessen, K.A., Clow, D.W., Mast, M.A., Campbell, D.H., and Melack, J.M., 2001, Major-ion chemistry of the Rocky Mountain snowpack, USA: Atmospheric Environment, v. 35, p. 3957–3966.

Publishing support provided by:
Denver Publishing Service Center

For more information concerning this publication contact:
Center Director, USGS Colorado Water Science Center
Box 25046, Mail Stop 415
Denver, CO 80225
(303)236-4882

Or visit the Colorado Water Science Center Web site at:
http://co.water.usgs.gov