

Prepared in Cooperation with the U.S. Environmental Protection Agency

## **Selected Water-Quality Data for the Standard Mine, Gunnison County, Colorado, 2006-2007**



Open-File Report 2007–1241

**Front Cover:** View of the Standard Mine facilities near Crested Butte, Colorado, taken from the Level 1 portal, July 2005.

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By Philip L. Verplanck, Andrew H. Manning, M. Alisa Mast, Richard B. Wanty,  
R. Blaine McCleskey, Todor Todorov, and Monique Adams

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**U.S. Department of the Interior**  
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# Contents

|  |    |
|--|----|
| Abstract.....                              | 1  |
| Introduction.....                          | 1  |
| Location and Climate.....                  | 1  |
| Purpose and Scope.....                     | 1  |
| Acknowledgments.....                       | 4  |
| Methods.....                               | 4  |
| Sampling Sites.....                        | 4  |
| Water-Chemistry Sampling.....              | 9  |
| Laboratory Methods.....                    | 9  |
| Quality Assurance and Quality Control..... | 11 |
| References Cited.....                      | 12 |

## Figures

|   |    |
|---|----|
| 1. Index map of Colorado with expanded view showing the Standard Mine.....  | 2  |
| 2. Topographic map of Elk Basin and vicinity.....   | 3  |
| 3. Cross-sectional view of the Standard Mine workings.....  | 5  |
| 4. Aerial photograph of Elk Basin showing surface-sample sites.....   | 6  |
| 5. Level 3 of the Standard Mine showing sample sites.....   | 7  |
| 6. Level 5 of the Standard Mine showing sample sites.....   | 8  |
| 7. Comparison of analytical results by ICP-AES and ICP-MS with A, barium concentration, B, manganese concentration, and C, strontium concentration..... | 11 |

## Tables

|  |  |
|--|--|
| 1. Sample site locations.....                    | 4  |
| 2. Methods of analysis and detection limits..... | 10   |
| 3. Water analyses of study samples.....          | <a href="#">click here to open table 3</a> |
| 4. ICP-MS analyses of study samples.....         | <a href="#">click here to open table 4</a> |

## Conversion Factors

### Inch/Pound to SI

| Multiply                      | By      | To obtain  |
|-------------------------------|---------|--|
| Length                        |         |  |
| inch (in.)                    | 25,400. | micrometer ( $\mu\text{m}$ )                     |
| foot (ft)                     | 0.3048  | meter (m)  |
| mile (mi)                     | 1.609   | kilometer (km)                                   |
| Area                          |         |  |
| square mile ( $\text{mi}^2$ ) | 259.0   | hectare (ha)                                     |
| square mile ( $\text{mi}^2$ ) | 2.590   | square kilometer ( $\text{km}^2$ )               |
| Volume                        |         |  |
| cubic inch ( $\text{in}^3$ )  | 16,390. | microliter ( $\mu\text{L}$ )                     |
| Flow rate                     |         |  |
| inch per year (in/yr)         | 25.4    | millimeter per year (mm/yr)                      |
| acre-foot per day (acre-ft/d) | 0.01427 | cubic meter per second ( $\text{m}^3/\text{s}$ ) |

Temperature in degrees Celsius ( $^{\circ}\text{C}$ ) may be converted to degrees Fahrenheit ( $^{\circ}\text{F}$ ) as follows:  

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at  $25^{\circ}\text{C}$ ). Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

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## Abstract

Mine drainage and underground water samples were collected for analysis of inorganic solutes as part of a 1-year, hydrogeologic investigation of the Standard Mine and vicinity. The U.S. Environmental Protection Agency has listed the Standard Mine in the Elk Creek drainage near Crested Butte, Colorado, as a Superfund Site because discharge from the Standard Mine enters Elk Creek, contributing dissolved and suspended loads of zinc, cadmium, copper, and other metals to Coal Creek, which is the primary drinking-water supply for the town of Crested Butte.

Water analyses are reported for mine-effluent samples from Levels 1 and 5 of the Standard Mine, underground samples from Levels 3 and 5 of the Standard Mine, mine effluent from an adit located on the Elk Lode, and two spring samples that emerged from waste-rock material below Level 5 of the Standard Mine and the adit located on the Elk Lode. Reported analyses include field parameters (pH, specific conductance, water temperature, dissolved oxygen, and redox potential) and major constituents and trace elements.

## Introduction

In 2006, the U.S. Environmental Protection Agency (USEPA) listed the Standard Mine in the Elk Creek drainage basin near Crested Butte, Colorado (fig. 1) as a Superfund Site because drainage from the Standard Mine enters Elk Creek, contributing dissolved and suspended loads of zinc, cadmium, copper and other metals to the stream. Elk Creek flows into Coal Creek, which is the main drinking-water supply for the town of Crested Butte. As part of the site characterization, the U.S. Geological Survey (USGS) was asked to characterize the ground-water flow system in the vicinity of the Standard Mine in order to assist the USEPA in evaluating remedial options for the mine. One aspect of the study was to collect water-quality samples from mined areas within the Elk Creek drainage.

## Location and Climate

The Standard Mine lies within the upper Elk Creek drainage basin (Elk Basin), a roughly 1-mi<sup>2</sup> alpine watershed located approximately 4 mi west-northwest of the town of Crested Butte in west-central Colorado (fig. 1). Land-surface elevations in Elk Basin range from 10,800 to 12,200 ft, and topographic gradients generally range from 0.2 to 0.6, typical of rugged mountain settings (fig. 2). Vegetation is subalpine to alpine, dominantly mixed spruce and fir forest or tundra. The closest meteorological stations are in the town Crested Butte at an elevation of 8,860 ft (<http://www.wrcc.dri.edu>) and at Crested Butte Ski Area about 6 mi to the east at an elevation of 10,160 ft (<http://www.wcc.nrcs.usda.gov/snotel>). Data from these stations indicate that Elk Basin has a mean annual air temperature of about 1°C and mean annual precipitation of about 31 in/yr, with about 65 percent of precipitation typically falling as snow. Snow cover generally persists from November through May. Elk Basin is drained by Elk Creek, a perennial stream and a tributary to Coal Creek.

## Purpose and Scope

The purpose of this report is to present water-quality data from the ground-water investigation conducted from July 2006 to June 2007 in Elk Basin, Colorado. Use of these data will aid in characterization of the ground-water system in the study area. Data presented in this report include field measurements of pH, specific conductance, dissolved oxygen, redox potential (Eh), and water temperature; and laboratory determinations of major constituent and selected trace element concentrations. Water samples include seasonal sampling of the Standard Mine drainage, ground-water samples from inside the Standard Mine, Elk Mine effluent, and selected springs that emerge from waste-rock material.

2 Selected Water-Quality Data for the Standard Mine, Gunnison County, Colorado, 2006-2007

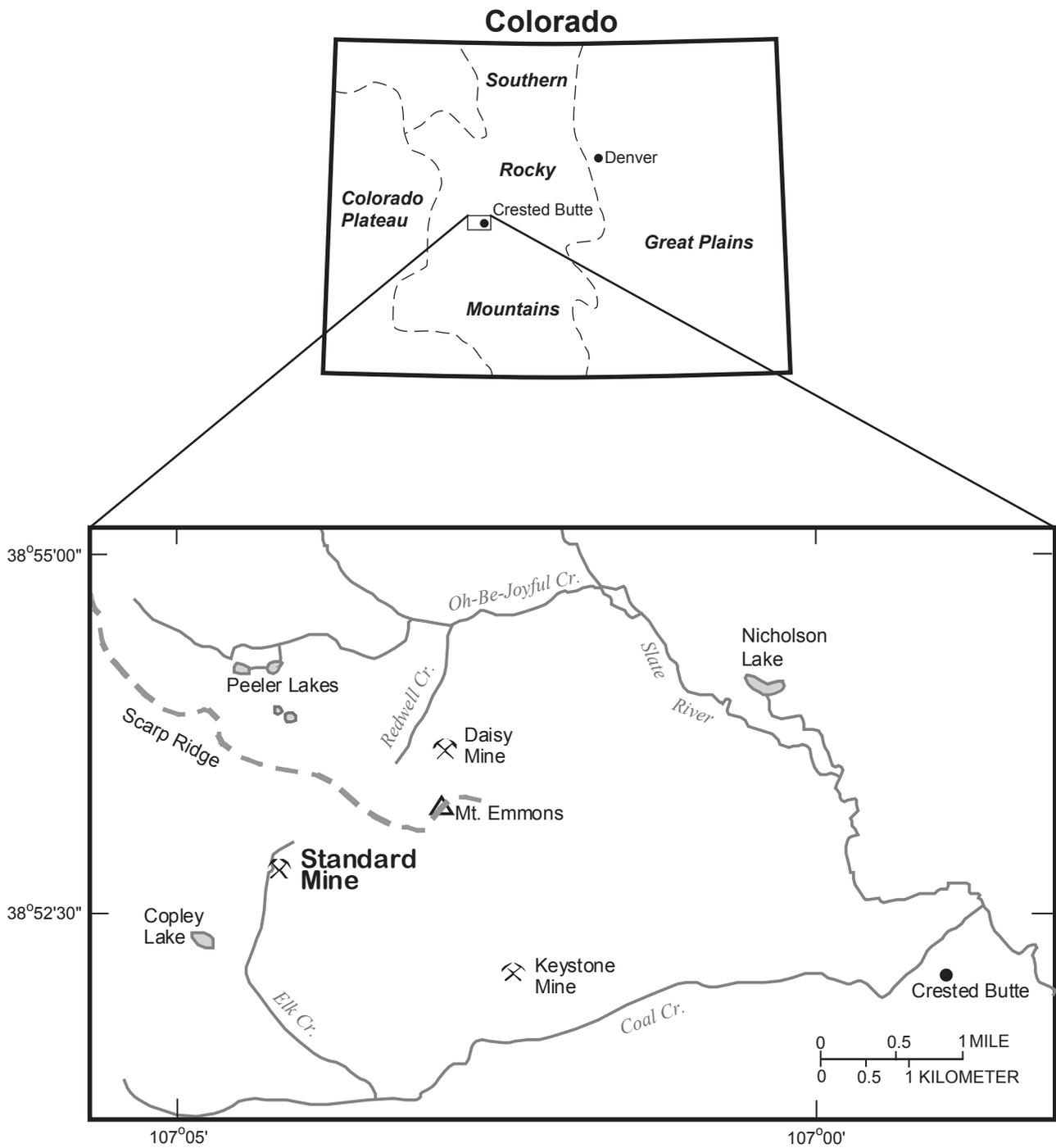


Figure 1. Index map of Colorado with expanded view showing location of the Standard Mine.

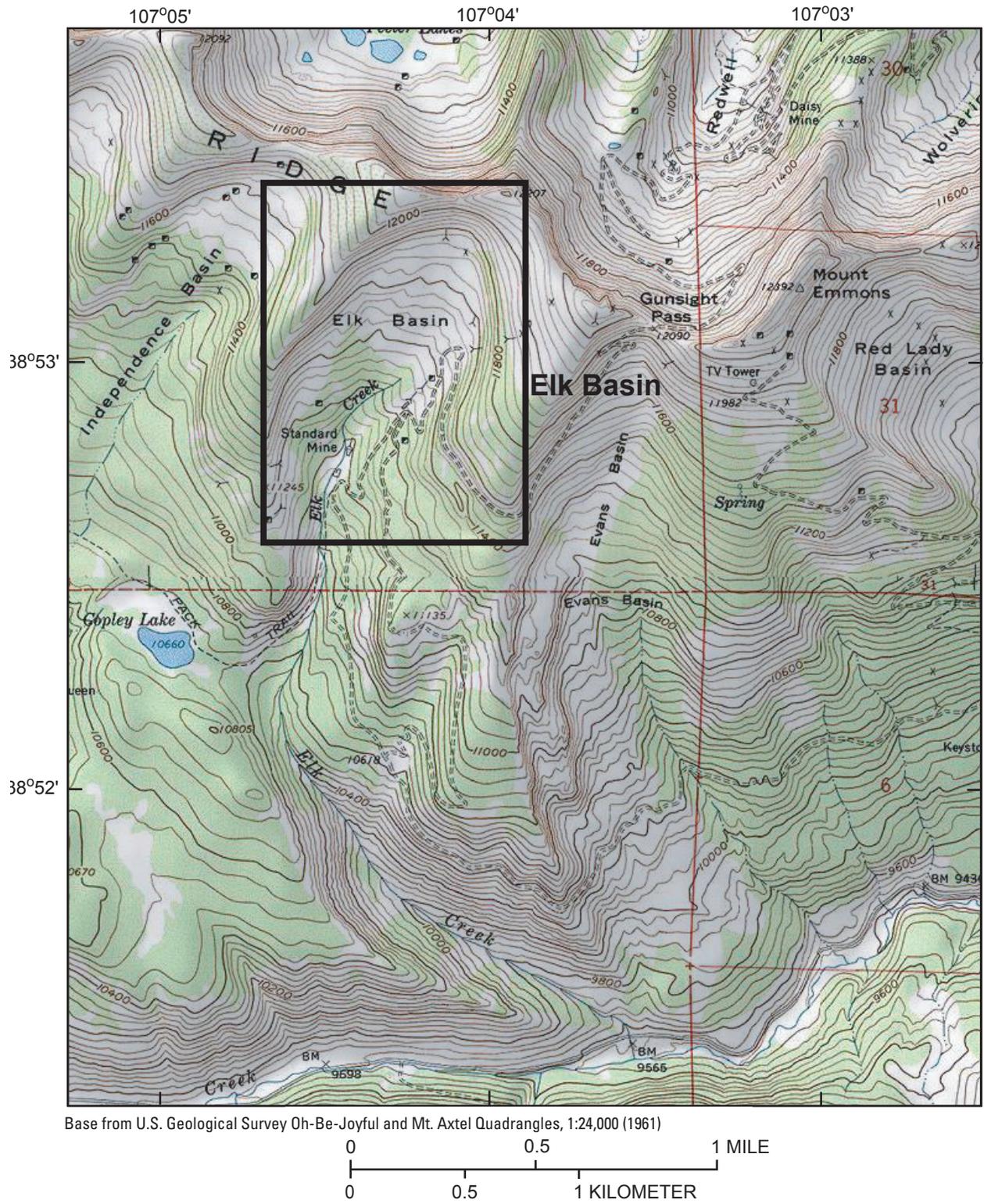


Figure 2. Topographic map of Elk Basin and vicinity.

## Acknowledgments

This work was done in cooperation with the USEPA. We greatly appreciate the efforts of Steve Renner, Jim Herron, and Jeff Graves of the Colorado Division of Reclamation, Mining, and Safety (CDRMS) for escorting us into the mine. We thank David L. Fey and JoAnn M. Holloway of the USGS for their constructive comments during the preparation and review of this report.

## Methods

### Sampling Sites

The largest mine within Elk Basin is the Standard Mine, which consists of five levels with multiple stopes and raises. A more-detailed description of the Standard Mine is provided in a Colorado Geological Survey report on the mine (Bird and Wood, undated). The adits are designated Levels 1, 2, 3, and 5, in sequence from lowermost to uppermost (fig. 3). Levels

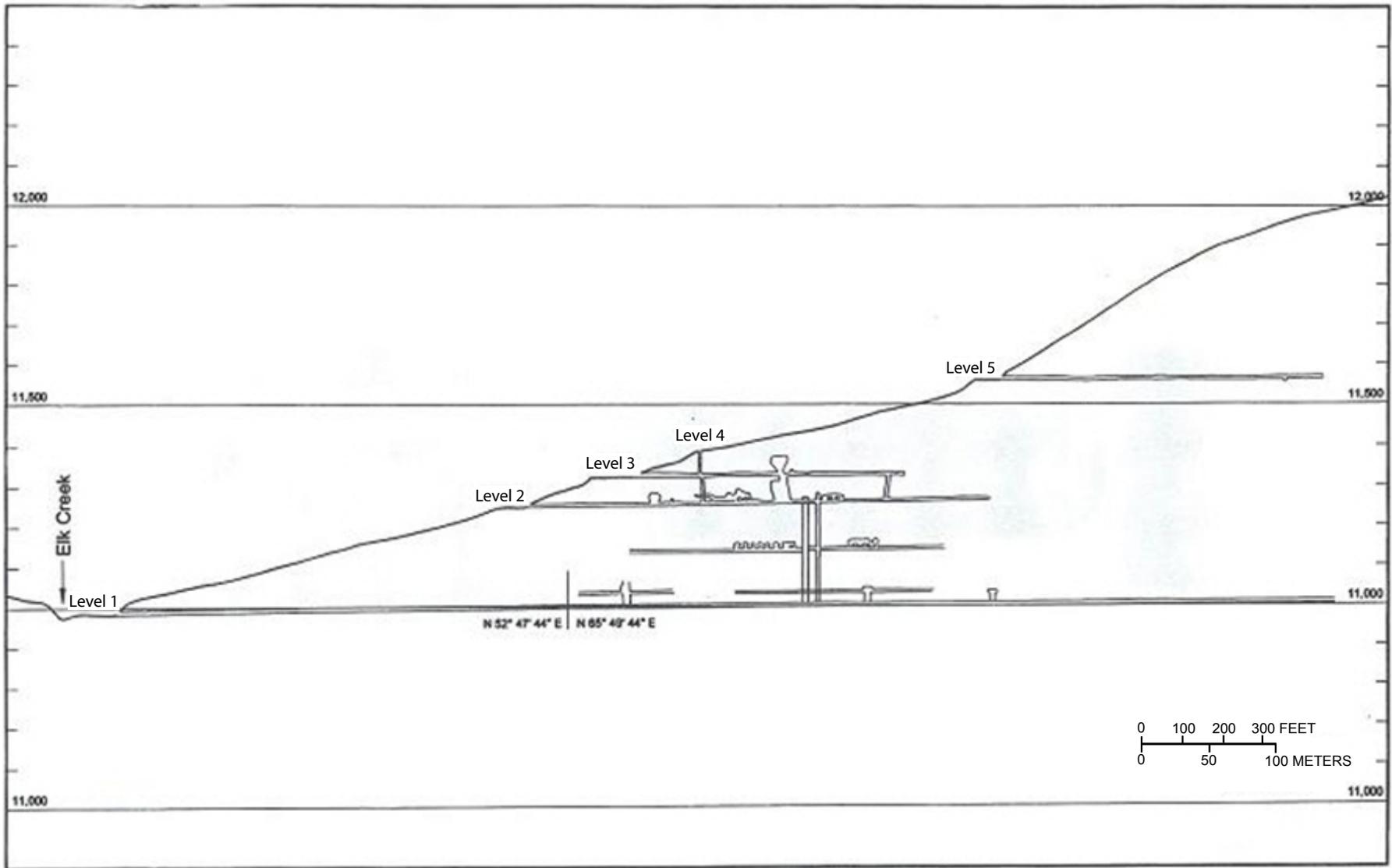
1, 2, and 3 are connected by a series of raises. The Level 5 tunnel, however, is not connected to the other levels. The Level 1 and Level 5 portals are the only portals that consistently drain water. In August 2006, water was observed in Level 3 and drained to lower levels via raises.

Table 1 and figure 4 provide the locations of surface samples. Figures 5 and 6 show the location of samples collected inside the Standard Mine. Sample collection of the Level 1 portal (EC-MSTD1) was the most comprehensive and included samples in July, August, and October 2006 and February, March, April, May, and June 2007. In July 2006, a seep emanating from waste-rock material near the caved entrance to Level 2 was collected (EC-MUSTD1). In August 2006, five samples from Level 3 (EC-MSTD131 through 35) were collected between 132 and 639 ft in from the entrance (fig. 5), three samples from Level 5 (fig. 6) including the adit effluent (EC-M11600) and two inside the mine (EC-M116001 and 2), a seep emanating from waste-rock material below the Level 5 adit (EC-S1), one sample from the collapsed Elk Lode portal (EC-M11400B), and one sample from waste-rock material below the Elk Lode (EC-S11).

**Table 1.** Sample site locations.

[Ft, feet; UG, underground ;m, meter; coordinates are Universal Transverse Mercator (UTM) coordinate system, North American Datum of 1983, Zone 13S]

| Site name  | Northing (m) | Easting (m) | Description  | Elevation (Ft) |
|------------|--------------|-------------|--|----------------|
| EC-MSTD1   | 4305516.8    | 320123.7    | Standard Mine, Level 1-portal                                | 11,008         |
| EC-MUSTD1  | 4305674.2    | 320315.2    | Standard Mine, Level 2-waste-rock seep near collapsed portal | 11,208         |
| EC-MSTD131 | UG           | UG          | Standard Mine, Level 3-132 ft in from portal                 | UG             |
| EC-MSTD132 | UG           | UG          | Standard Mine, Level 3-145 ft in from portal                 | UG             |
| EC-MSTD133 | UG           | UG          | Standard Mine, Level 3-327 ft in from portal                 | UG             |
| EC-MSTD134 | UG           | UG          | Standard Mine, Level 3-386 ft in from portal                 | UG             |
| EC-MSTD135 | UG           | UG          | Standard Mine, Level 3-639 ft in from portal                 | UG             |
| EC-M11600  | 4305941.1    | 320666.6    | Standard Mine, Level 5-portal                                | 11,581         |
| EC-M116001 | UG           | UG          | Standard Mine, Level 5-546 ft in from portal, left drift     | UG             |
| EC-M116002 | UG           | UG          | Standard Mine, Level 5-228 ft in from portal                 | UG             |
| EC-M11400B | 4305948.8    | 320403.8    | Elk Lode-portal  | 11,380         |
| EC-S1      | 4305935.9    | 320609.7    | Seep from base of waste-rock pile below Level 5 adit         | 11,509         |
| EC-S11     | 4305911.6    | 320345.2    | Seep at waste-rock pile below Elk Lode portal                | 11,356         |



**Figure 3.** Cross-sectional view of the Standard Mine workings. Sketch from U.S. Environmental Protection Agency.

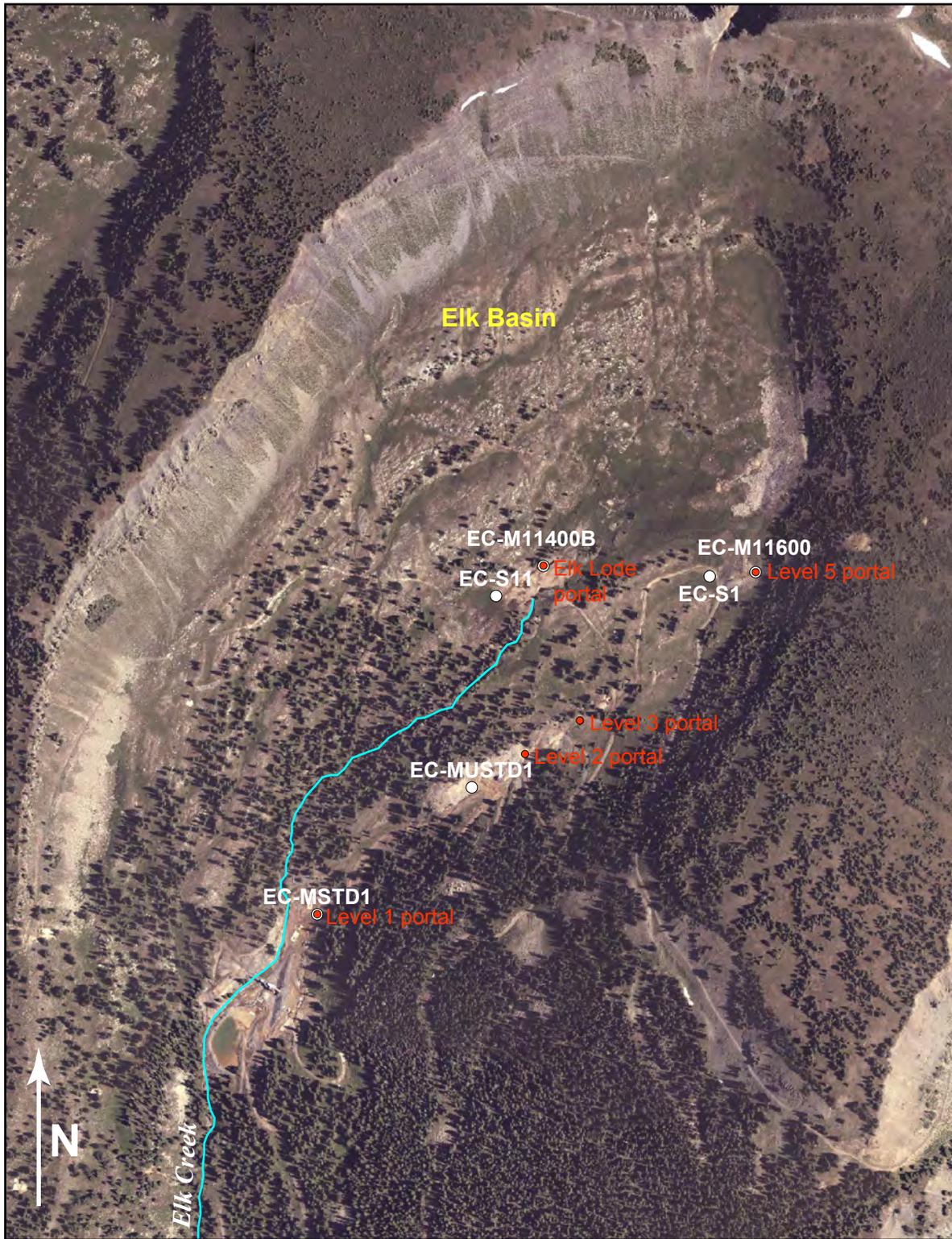


Figure 4. Aerial photograph of Elk Basin showing surface sample sites.

# LEVEL 3

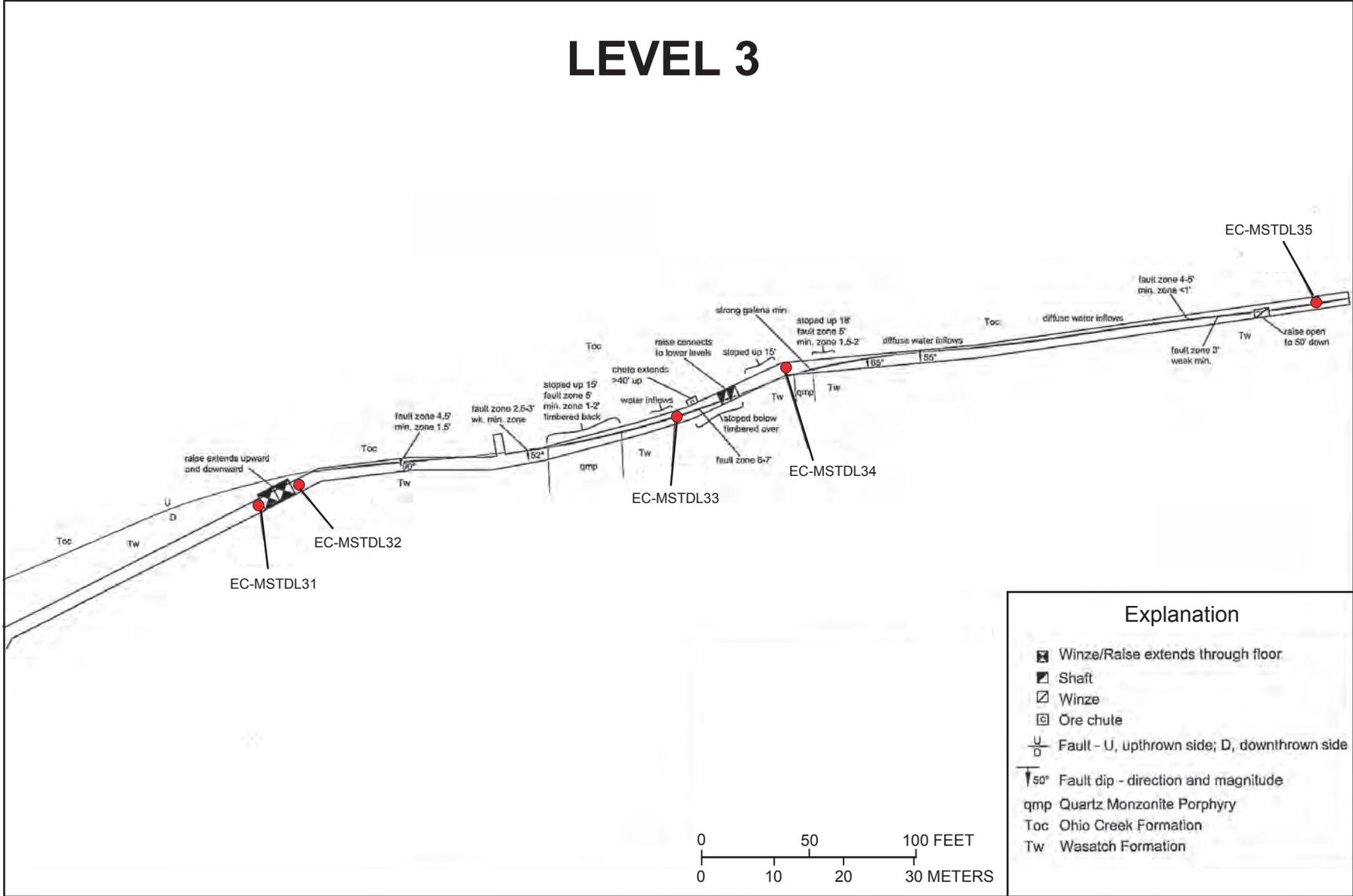


Figure 5. Level 3 of the Standard Mine showing sample sites. Draft mine map courtesy of Colorado Division of Reclamation, Mining, and Safety.

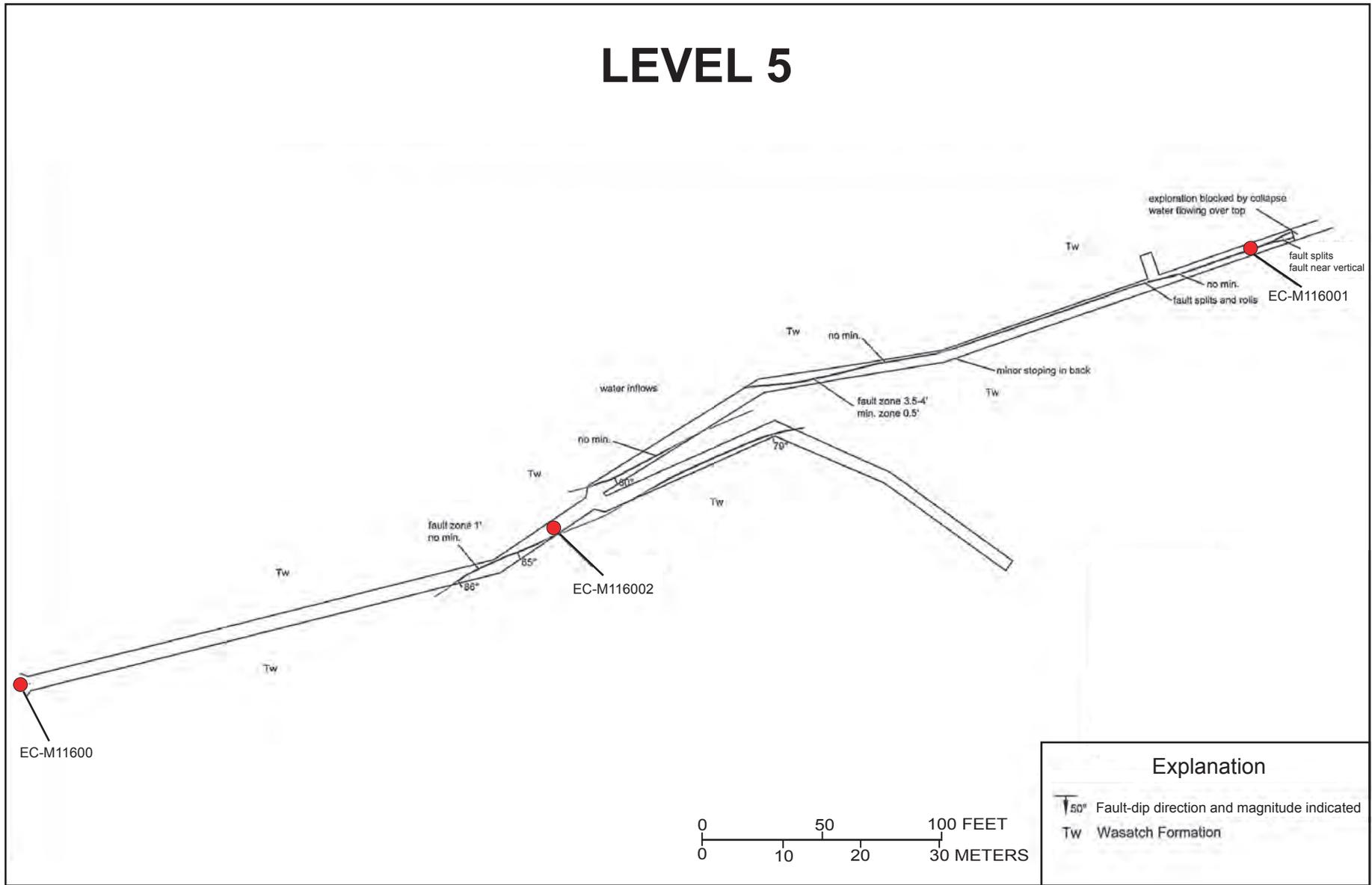


Figure 6. Level 5 of the Standard Mine showing sample sites. Draft mine map courtesy of Colorado Division of Reclamation, Mining, and Safety.

## Water-Chemistry Sampling

Onsite measurements of pH, specific conductance, temperature, dissolved oxygen, and Eh were obtained. At each site the pH electrode calibration was checked and, when necessary, recalibrated using two buffers that bracketed the measured pH. Samples were filtered onsite through a syringe filter having a pore size of 0.45  $\mu\text{m}$ . Several sample aliquots were collected for determination of concentrations of inorganic constituents and redox species ( $\text{Fe}^{+2}/\text{Fe}^{+3}$ ). Container preparation and stabilization of filtered samples included an unfiltered, nitric acid acidified aliquot (RA) for total-recoverable major cation and trace element determinations; a filtered, nitric acid acidified aliquot (FA) for dissolved major cation and trace element determinations; a filtered, nonacidified aliquot (FU) for anion and alkalinity determinations; and a filtered, hydrochloric acid acidified aliquot for iron redox species determinations. Bottles for FA and RA aliquots were presoaked in nitric acid, rinsed in distilled water, and prerinsed with sample water. Bottles for FU aliquots were presoaked in distilled water and prerinsed with sample water. Opaque bottles for iron redox aliquots were presoaked in hydrochloric acid, rinsed in distilled water, and prerinsed with sample water. Appropriate aliquots were acidified with ultrapure acid and then stored on ice until refrigerated.

## Laboratory Methods

All reagents were of a purity at least equal to the reagent-grade standards of the American Chemical Society. Double-distilled deionized water, and re-distilled acids using a sub-boiling purification technique (Kuehner and others, 1972), were used in all preparations. The methods and detection limit

for each analysis are summarized in table 2. USGS standard reference water samples and blanks were included with each sample suite for inductively coupled plasma atomic-emission spectroscopy (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS). Major cations (Ca, Mg, K, and Na) and silica and selected trace elements (aluminum, boron, barium, copper, iron, manganese, lead, strontium, and zinc) for total-recoverable and dissolved samples were determined using a Perkin Elmer Optima 3000<sup>TM</sup> ICP-AES (Briggs, 2002). Trace elements for total-recoverable and dissolved samples were analyzed with the ICP-MS using a method developed by the U.S. Geological Survey (Meier and others, 1994; Lamothe and others, 2002). This method is used to directly determine the elements in the water samples without need for any preconcentration or dilution. Elemental detection limits are in the sub-parts per billion range (table 2), and the working linear range is six or more orders of magnitude.

Concentrations of major anions ( $\text{Cl}^-$ ,  $\text{F}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ ) were determined by ion chromatography (Theodorakos and others, 2002) using a Dionex DX500<sup>TM</sup> ion chromatograph with 5- $\mu\text{L}$  and 10- $\mu\text{L}$  sample loops. Standards were prepared from compounds of the highest commercially available purity. USGS standard reference water samples were used as independent quality-control standards. Alkalinity (as  $\text{HCO}_3^-$ ) was determined using an Orion 960<sup>TM</sup> autotitrator and standardized  $\text{H}_2\text{SO}_4$  (Barringer and Johnsson, 1989). Samples were diluted as necessary to bring the analyte concentration within the optimal range of the method. Iron (II) redox species and total iron, in filtered, HCl-acidified samples, were determined using a modification of the FerroZine<sup>TM</sup> colorimetric method (Stookey, 1970; To and others, 1999) with a Hewlett Packard 8453<sup>TM</sup> diode array ultraviolet/visible (UV/VIS) spectrophotometer.

**10 Selected Water-Quality Data for the Standard Mine, Gunnison County, Colorado, 2006-2007**

**Table 2.** Methods of analysis and detection limits

[mg/L, milligram per liter; µg/L, microgram per liter; IC, ion chromatography; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-AES, inductively coupled plasma-atomic emission spectroscopy]

| Element         | Detection limit | Method    | Element                      | Detection limit | Method  |
|-----------------|-----------------|-----------|------------------------------|-----------------|---------|
| Ag              | 1 µg/L          | ICP-MS    | Mn                           | 0.2 µg/L        | ICP-MS  |
| Al              | 20 µg/L         | ICP-AES   | Mo                           | 2 µg/L          | ICP-MS  |
| Al              | 2 µg/L          | ICP-MS    | Na                           | 0.1 mg/L        | ICP-AES |
| As              | 1 µg/L          | ICP-MS    | Nb                           | 0.2 µg/L        | ICP-MS  |
| B               | 5 µg/L          | ICP-AES   | Nd                           | 0.01 µg/L       | ICP-MS  |
| Ba              | 1 µg/L          | ICP-AES   | Ni                           | 0.4 µg/L        | ICP-MS  |
| Ba              | 0.2 µg/L        | ICP-MS    | NO <sub>3</sub> <sup>-</sup> | 0.05 mg/l       | IC      |
| Be              | 0.05 µg/L       | ICP-MS    | P                            | 10 µg/L         | ICP-MS  |
| Bi              | 0.2 µg/L        | ICP-MS    | Pb                           | 50 µg/L         | ICP-AES |
| Ca              | 0.1 mg/L        | ICP-AES   | Pb                           | 0.05 µg/L       | ICP-MS  |
| Cd              | 0.02 µg/L       | ICP-MS    | Pr                           | 0.01 µg/L       | ICP-MS  |
| Ce              | 0.01 µg/L       | ICP-MS    | Rb                           | 0.01 µg/L       | ICP-MS  |
| Cl <sup>-</sup> | 0.05 mg/l       | IC        | Sb                           | 0.3 µg/L        | ICP-MS  |
| Co              | 0.02 µg/L       | ICP-MS    | Sc                           | 0.6 µg/L        | ICP-MS  |
| Cr              | 1 µg/L          | ICP-MS    | Se                           | 1 µg/L          | ICP-MS  |
| Cs              | 0.02 µg/L       | ICP-MS    | SiO <sub>2</sub>             | 0.1 mg/L        | ICP-AES |
| Cu              | 10 µg/L         | ICP-AES   | SO <sub>4</sub> <sup>-</sup> | 0.05 mg/l       | IC      |
| Cu              | 0.5 µg/L        | ICP-MS    | Sm                           | 0.01 µg/L       | ICP-MS  |
| Dy              | 0.005 µg/L      | ICP-MS    | Sr                           | 1 µg/L          | ICP-AES |
| Er              | 0.005 µg/L      | ICP-MS    | Sr                           | 0.5 µg/L        | ICP-MS  |
| Eu              | 0.005 µg/L      | ICP-MS    | Ta                           | 0.02 µg/L       | ICP-MS  |
| F <sup>-</sup>  | 0.05 mg/l       | IC        | Tb                           | 0.005 µg/L      | ICP-MS  |
| Fe              | 20 µg/L         | ICP-AES   | Th                           | 0.2 µg/L        | ICP-MS  |
| Fe              | 2 µg/L          | FerroZine | Ti                           | 0.5 µg/L        | ICP-MS  |
| Fe (II)         | 2 µg/L          | FerroZine | Tl                           | 0.15 µg/L       | ICP-MS  |
| Ga              | 0.05 µg/L       | ICP-MS    | Tm                           | 0.005 µg/L      | ICP-MS  |
| Gd              | 0.005 µg/L      | ICP-MS    | U                            | 0.1 µg/L        | ICP-MS  |
| Ge              | 0.05 µg/L       | ICP-MS    | V                            | 0.5 µg/L        | ICP-MS  |
| Ho              | 0.005 µg/L      | ICP-MS    | W                            | 0.5 µg/L        | ICP-MS  |
| K               | 30 µg/L         | ICP-MS    | Y                            | 0.01 µg/L       | ICP-MS  |
| La              | 0.01 µg/L       | ICP-MS    | Yb                           | 0.005 µg/L      | ICP-MS  |
| Li              | 0.2 µg/L        | ICP-MS    | Zn                           | 20 µg/L         | ICP-AES |
| Lu              | 0.1 µg/L        | ICP-MS    | Zn                           | 0.5 µg/L        | ICP-MS  |
| Mg              | 0.1 mg/L        | ICP-AES   | Zr                           | 0.2 µg/L        | ICP-MS  |
| Mn              | 10 µg/L         | ICP-AES   |                              |                 |         |

## Quality Assurance and Quality Control

Quality control included replicate samples, field equipment blanks, analyses by alternative methods, and calculation of charge imbalance. Replicate samples are two field-collected samples that are considered to be essentially identical in composition and are used to estimate variability in environmental data. Replicate samples were collected immediately following the environmental sample. Each replicate sample was processed through all the steps of the environmental sample using a new filter and clean equipment. Replicate samples were analyzed at the same time using the same instruments as the other samples collected during the same sampling trip. Analytical results of replicate samples are included in tables 3 and 4, and follow the corresponding water sample (sample name ending with R). Most major, minor, and trace element replicate concentrations are within  $\pm 10$  percent of the corresponding water-chemistry sample.

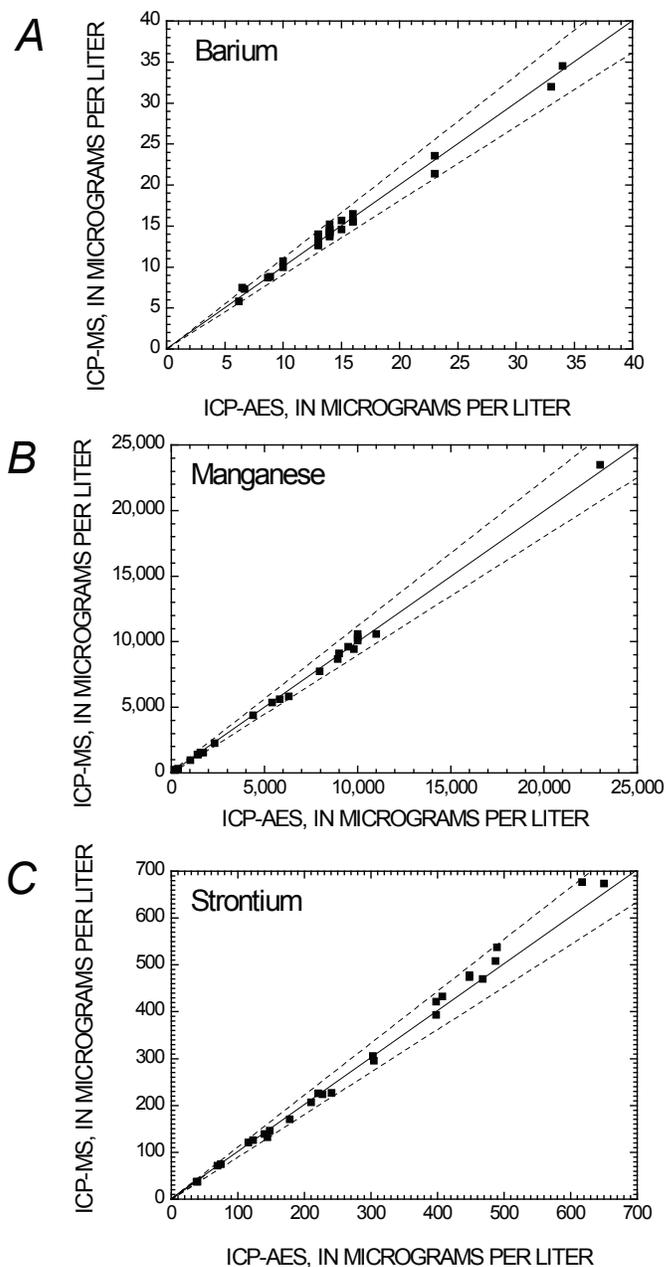
A field equipment blank is a sample prepared using deionized water passed through all the sampling and processing equipment. This type of sample is used to check for the potential contamination of the water-chemistry samples during collection, processing, handling, and analysis. Analytical results are included in tables 3 and 4, designated EB-01 through EB-05 (Equipment Blank). All analytes were below analytical detection limits except for bicarbonate alkalinity, which was consistently measured at 2 mg/L, just above the reporting limit.

Concentrations of cations were determined by ICP-AES and ICP-MS, and if concentrations of trace elements were at least three times the detection limit, good agreement between ICP-AES and ICP-MS results was observed (fig. 7). Barium, manganese, and strontium were chosen for this comparison because the range in concentrations of these elements was within the working range of both analytical techniques.

Data for all samples with complete analyses were checked using the computer program WATEQ4F (Ball and Nordstrom, 1991) for charge imbalance (C.I.), using the following calculation:

$$\text{C.I. (percent)} = \frac{100 * (\text{sum cations} - \text{sum anions})}{(\text{sum cations} + \text{sum anions})}$$

where sum cations is the sum of the cations in milliequivalents per liter, and sum anions is the sum of the anions in milliequivalents per liter. The percent-charge imbalance reflects how well the major anions and cations balance and usually is an independent measure of the accuracy of the analytical techniques. The percent-charge imbalance was low (less than 10 percent) for all samples (tables 3).



**Figure 7.** Comparison of analytical results by ICP-AES and ICP-MS with *A*, barium concentration, *B*, manganese concentration, and *C*, strontium concentration. Diagonal line is 1:1 correspondence and dashed lines indicate 10-percent variation.

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