# MONITORING AT THE ABANDONED ELIZABETH AND ELY MINES IN EASTERN VERMONT[1]

James V. Holmes,[2] Daniel E. Lawson, Kathleen D. White, and Scott E. Acone

**Abstract.** The complexities of remediation and restoration of abandoned mine lands with acid mine drainage require cost effective investigations that are coupled with in situ parameter measurements and monitoring, sometimes in near real-time. Off-the-shelf as well as innovative, state-of-the-art instrumentation and equipment can be readily adapted to site characterization and monitoring, and can be linked to various digital data transmission technologies for remote sites lacking power and easy access. Data, once received, can be readily displayed on web sites or incorporated into a GIS. At the Elizabeth and Ely abandoned mine sites in Vermont, we have employed various types of instrumentation to monitor surface and ground water hydrology, meteorology and water chemistry, depending on the application. To characterize temporal variations in drainage sources and metal loading during spring runoff at Ely Mine, we used Hydrolab data sondes for in situ measures of water temperature, conductivity and pH at 20-minute intervals. For laboratory chemical analyses, we obtained water samples at timed intervals automatically using an ISCO suction sampler in conjunction with water level measurements using a pressure transducer in a calibrated weir. Stage, along with air and water temperatures and rainfall, were measured at 5-minute intervals and stored on a Campbell data logger powered by a battery charged by solar panels. At the Elizabeth Mine, acid mine discharge and various water quality parameters are monitored continuously at five remote sites, three near the points of discharge of seeps from tailings. Data are stored on Campbell data loggers and periodically transmitted via radio to a cell phone for transmission and rapid graphical display on a web site. In addition, we used ISCO samplers triggered by intense rainfall to collect water samples in 15-minute intervals, allowing us to characterize the total storm loading during summer thunderstorms.

Additional Key Words: in-situ measurements, copper mine, surface water hydrology, ground water hydrology, meteorology, acid runoff

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## Introduction

The Elizabeth Mine in Strafford, VT is an abandoned copper and copperas (iron sulfate) mine that was discovered in 1793 and worked intermittently for nearly 150 years (PAL, 2001). Historic operations generated over 20 hectares of waste rock and tailings materials that were deposited in three primary piles on the site. Tailings piles 1 and 2 (Fig. 1) at Elizabeth Mine cover 14 hectares and have largely filled a previously existing valley. The tailings in these piles are waste from ore processing in the 1940s and 1950s. The largest, tailings pile 1 (TP-1), is over 30 meters maximum thickness and exhibits several seeps along its northern base. TP-3 comprises waste rock and heap leach piles from the 19$^{th}$ century. It covers only 2.5 hectares but is highly contaminated (PAL, 2001; ADL, 2001).

Acid mine drainage (AMD), containing elevated metals concentrations and high silt content, results from surface water and ground water interaction with these waste materials (Seal et al., 2001). Sampling has demonstrated that the Elizabeth Mine contributes contaminants to the West Branch of the Ompompanoosuc River, resulting in metals concentrations that exceed Vermont Water Quality Criteria. Aquatic bio-assessments show an adverse effect of the Elizabeth Mine drainage on biota in Copperas Brook, Lord Brook, and the West Branch of the Ompompanoosuc River downstream from the confluence of Copperas Brook (Barg et al., 1999).

The abandoned Ely Copper Mine on Beanville Road in Vershire, VT, comprises about 730 hectares, of which 110-140 hectares were used for mining operations between 1821 and 1920. Copper was produced here intermittently from 1820 to 1853, but from 1854 to 1882 the Ely Mine was one of the largest copper operations in the country (Donovan, 2001; Kierstead, 2001; PAL, 2001). Peak production occurred between 1879 and 1882. Mining activities included ore extraction, crushing and smelting on-site (Donovan, 2001). In the late 1940s, some Ely Mine waste was transported to Elizabeth Mine for reprocessing. Various mine wastes now remain at the Ely Mine site, including 1.7 hectares of smelter waste on the south side of the site, and 4.4 hectares of waste rock and tailings mounded in the center of the site (Fig. 2). The Bureau of Mines once estimated that over 90,000 tonnes of mine waste was generated on the property (U.S. EPA, 2001a). Like other mines in the Vermont copper belt including the Elizabeth Mine, the Ely

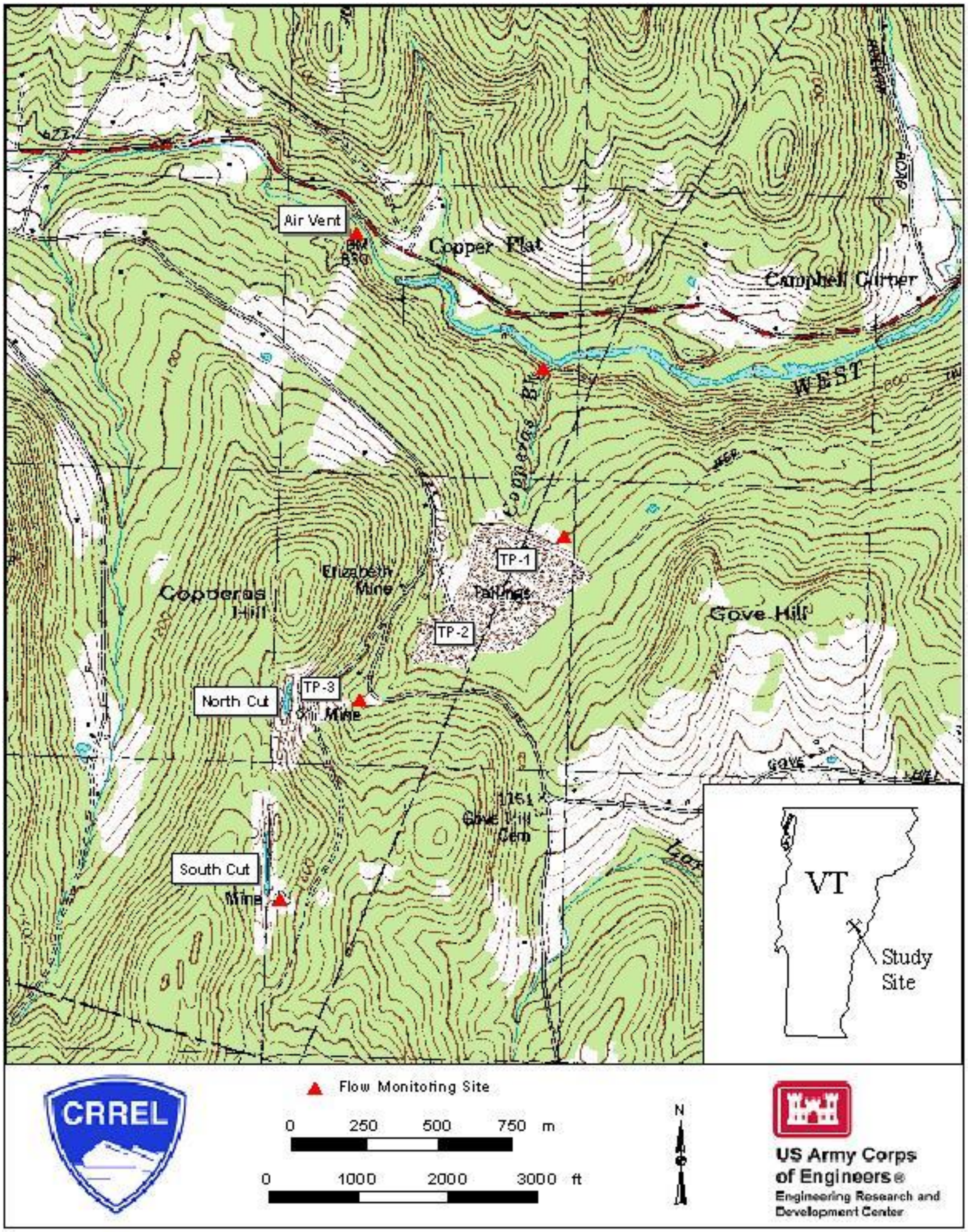


Figure 1. The Elizabeth Copper Mine and surrounding areas, South Strafford, VT. The triangles locate the discharge monitoring sites.

Mine produces metals-laden, acid-mine drainage (Seal et al., 2001). Preliminary data indicate that the concentrations of metals in surface water are highly elevated compared to background concentrations, and that these concentrations may be sufficient to impact the surface waters that receive the mine runoff (U.S. EPA, 2001a).

The U.S. Environmental Protection Agency (EPA), at the request of the Vermont Agency of Natural Resources (VTANR), became involved at the Elizabeth Mine in the fall of 1999. In February 2000, EPA requested that the U.S. Army Corps of Engineers, New England District (NAE), provide engineering support at Elizabeth Mine. Since that time, both NAE and the U.S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL) have been working with EPA to maintain programs at both the Elizabeth and Ely mines that address the community concerns, define the contamination at the sites and the impacts to human health and the environment, and develop alternatives to remediate contamination as appropriate. Elizabeth and Ely mines were placed on the National Priorities List (e.g., became Superfund sites) on June 14 and September 13, 2001, respectively. Because of their geological similarities, Elizabeth and Ely mines could be expected to share many similarities in their environmental signatures and overall impact. However, because of differences in ore-processing techniques and the hydrologic setting of the mine workings and waste material, significant differences exist between the sites' environmental settings.

In this paper, we describe the basic monitoring techniques used at Ely and Elizabeth Copper Mines to study contaminant loading and concentrations in the surface drainages of each site. We employed relatively inexpensive techniques for in situ measurement, sampling and data collection, including battery-powered data loggers charged by solar cells. In addition at one site, we transmitted data via remote radios connected to multiple data loggers to a centralized cellular phone that then transmitted these data daily to a computer at our lab, where it was automatically downloaded into a database for display on a password-protected web site.

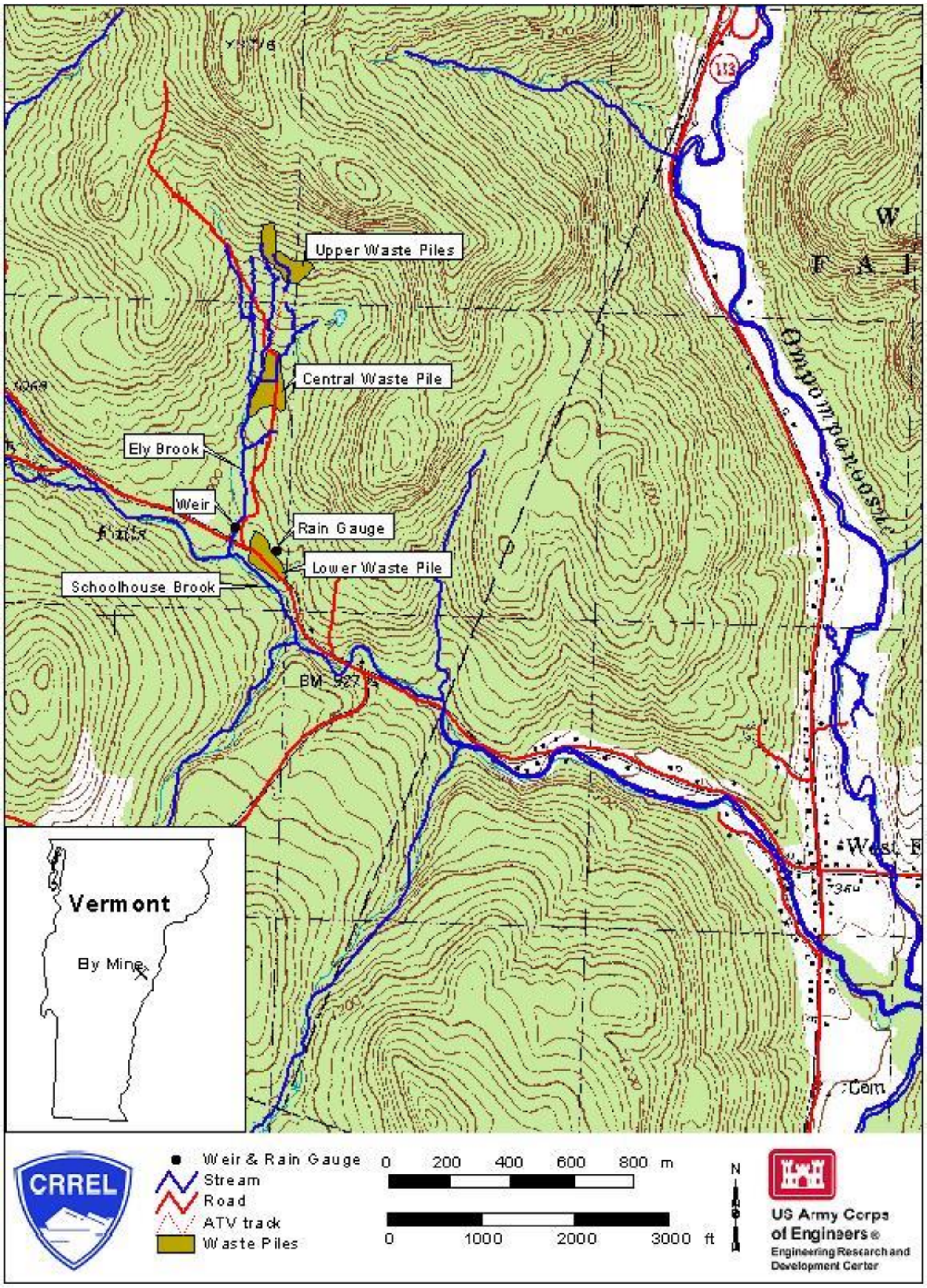


Figure 2. The Ely Copper Mine area, Vershire, VT.

## **Monitoring**

### Ely Mine

Spring 2002 runoff sampling was conducted at Ely Mine to determine total metals loading from the mine drainage of Ely Brook to the receiving waters of Schoolhouse Brook, and to characterize the downstream extent of contamination (Fig. 2). To ensure that we collected sufficient data within a tight budget, we utilized self-logging automated equipment as much as possible. Our first step comprised building a 90° v-notch weir in a well-confined channel near the mouth of Ely Brook (Fig. 3). We installed a 0.07-bar Druck depth-level transducer to measure stage within the impoundment and a thermistor to measure water temperature. Data from both were then recorded at 5-min intervals using a Campbell CR10X data logger. Power requirements were minimal with this setup, so a 12-volt battery charged by a 30-watt solar panel was adequate.

Figure 3. The 90° v-notch weir near the mouth of Ely Brook, Vershire, VT, prior to spring runoff in 2002.

Velocity is often assumed to be negligible for a v-notch weir, so discharge can be computed (in English units, per U.S. Geological Survey protocol) as

$$Q = 2.5(\tan \theta/2)h^{5/2} \qquad \textbf{(1)}$$

where Q = discharge (cfs), θ = angle of v-notch, and h = stage height (ft) (Rantz et al., 1982).

We used Hydrolab data sondes to monitor water temperature, pH, and specific conductance (SC) at three other sites. We were able to roughly correlate the pH and SC data with water chemistry data determined from sampling and laboratory analysis, allowing us to infer the loading of heavy metals into the system when time and budget prevented us from collecting additional water samples. At two locations – the mouth of Ely Brook and below the mixing zone in Schoolhouse Brook (Fig. 2) – we used the Hydrolab MiniSonde4a, a small, lightweight sonde (Fig. 4) to collect data in 20-minute intervals. The AA battery packs in these minisondes provided power to the units for about one month during which time all data were stored internally. We downloaded the data each time the batteries were replaced. At the most down-stream site, we

Figure 4. A Hydrolab MiniSonde 4a deployed near the mouth of Ely Brook, Vershire, VT, prior to spring runoff, 2002. The sonde is tethered to immovable objects in case of flooding.

used a Hydrolab DataSonde 3. The internal batteries last less than one week in this sonde, requiring an external battery pack mounted on the stream bank.

We used an ISCO automated water sampler to collect hourly water samples at each of the three Hydrolab sonde locations. We deployed these samplers to determine total metals loading during a 24-hour period representative of spring runoff (automated samplers cannot provide samples for dissolved metals) and the downstream extent of that load. We targeted a warm day during spring when discharge would rise considerably due to snowmelt. The samples were analyzed for metals concentrations and then correlated with the pH and/or the SC data from the Hydrolab sondes. In the AMD-dominated Ely Brook, we saw a strong correlation ($r^2 > 0.7$, $p << 0.001$) between SC and several metals, including Cu and Zn (Fig. 5). This correlation allowed us to make a first-order estimate of spring runoff metals loading without collecting and analyzing an inordinate number of water samples, which we were unable to do within budget.

Elizabeth Mine

During the 2003 field season, our first objective at Elizabeth Mine was to collect continuous flow data from five separate locations within the mine drainage. In addition, we automated the transmission of daily flow data from the field to our offices, where the data were uploaded to a password-protected web site. This reduced the number of trips to the site and allowed us to monitor the operation of the instruments.

We were also tasked to characterize storm runoff from TP-3, a steep, devegetated, highly erosive section of the upper mine area. Funding constraints required frugality. Our first task required us to install or rehabilitate flow devices at five separate locations within the mine drainage (Fig. 1). Two of these locations had pre-existing flow devices that were installed by the U.S. Geological Survey in the 1990s and that now were in disrepair. One of the restored devices is used to sample water discharging under an artesian head from a mine air vent. Mine water is stored in a pool and then decanted through a 7.6-cm Parshall flume to determine discharge (Fig. 6). We also restored a 61-cm Parshall flume at the mouth of Copperas Brook (Fig. 7).

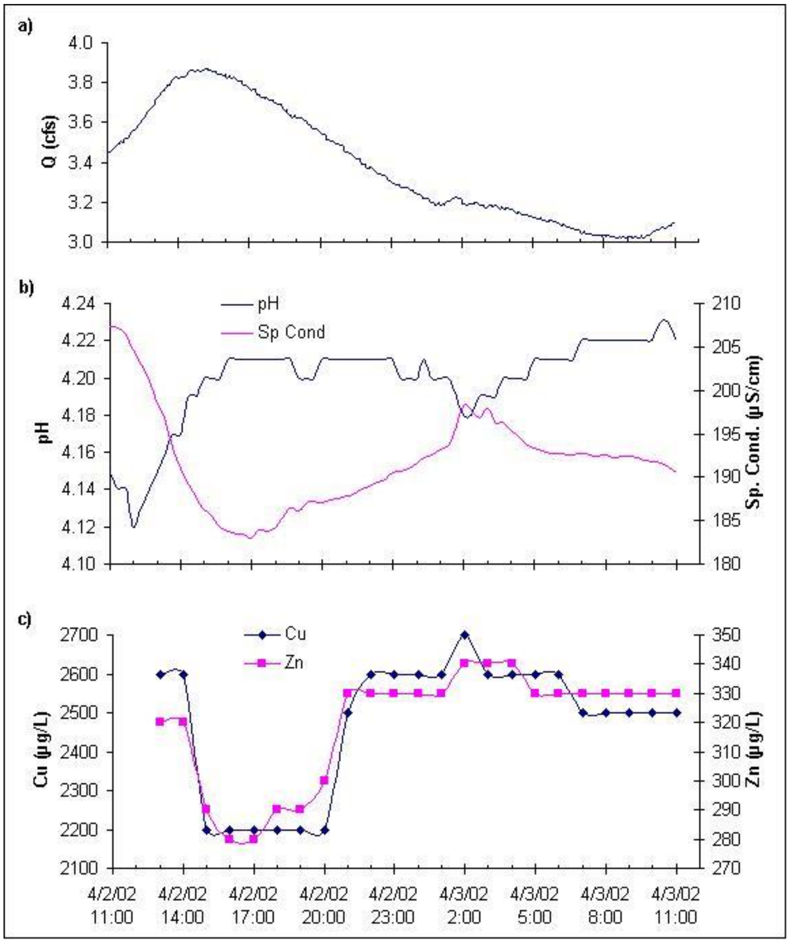


Figure 5. Ely Brook (a) discharge, (b) pH and specific conductivity, and (c) copper and zinc concentrations during the 24-hour sampling from April 2 to April 3, 2002

At the three flow sites located higher in the drainage (TP-1, TP-3, South Cut), we constructed weirs, including one 90° v-notch, one 120° v-notch, and one compound weir with a rectangular weir atop a 90° v-notch weir. The compound weir was sited in a location with low base flows but much higher flows during storm runoff that would exceed the capacity of the 90° v-notch weir. When flow exceeds the capacity of the v-notch, the discharge calculation is the sum of the flow through the v-notch (Eq. 1) and the flow through the rectangular weir, which is calculated as:

$$Q = K(W*0.2h)h^{1.5} \qquad \textbf{(2)}$$

where K = constant which depends on units and the ratio of the height of the weir to the depth of the impoundment, W = width of the weir (ft), and h = stage (ft) above the base of the rectangular weir (in English units, per U.S. Geological Survey protocol, Rantz et al., 1982).

Figure 6. Measuring flow at an artesian air vent, Elizabeth Mine, South Strafford, VT. Flow emerges into a moat, then decants through a pipe into a Parshall flume.

Figure 7. A Parshall flume at the mouth of Copperas Brook, South Strafford, VT. The U.S. Geological Survey originally installed the equipment at this site.

All five flow-monitoring sites were instrumented with Campbell pH and conductivity probes and Campbell CR10X data loggers powered by a 12-V battery and 50-W solar panel. Four of the five sites had 0.07-bar Druck depth-level transducers placed in the impoundment or stilling well for measuring stage. At the air vent site, we initially used a potentiometer to monitor water levels within the 7.6 cm flume. However, since we planned to continue collecting data at this site throughout the winter, we removed the potentiometer from the stilling well, where it could freeze, and placed it in a 10.2-cm PVC pipe mounted inside the flume and filled with Isopar oil to prevent freeze-up.

Figure 8. The instrumentation at the South Cut site, Elizabeth Mine, South Strafford, VT. This site contains a data logger, radio receiver for receiving data from other loggers at the site, and cellular transmitter for uploading all data to a database and web site at CRREL.

We transmitted the data from the field sites to the office at ERDC-CRREL using a cellular phone. We used RF telemetry (5-watt P50 Motorola VHF radios) to transmit data from the lower sites to the highest site at the South Cut (Fig. 1). One flow-monitoring site, located in a relatively flat, central location, received data from three other sites tucked deep within valleys. That central site relayed all data to the South Cut (Fig. 8), where the data were then transferred via analog cellular transmission (3-watt Motorola cell phone) to a computer with a modem at ERDC-CRREL. Data received at the office were uploaded to an online database and immediately made available on a password-protected web site (Fig. 9).

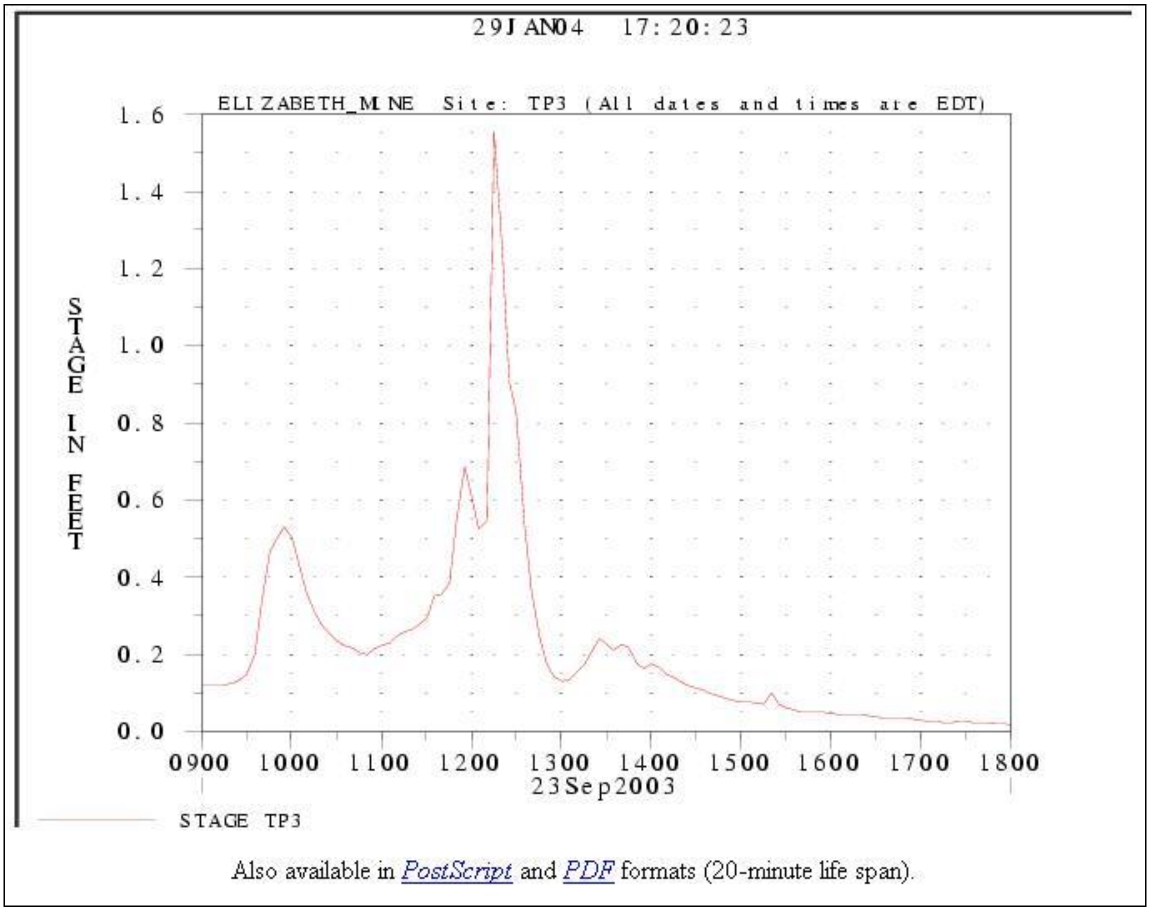


Figure 9. Example display from the web site that receives flow monitoring data from the Elizabeth Mine, South Strafford, VT. This example shows the hydrograph at site TP-3 during a storm event in September, 2003.

Flow monitoring data allowed us to identify a location within the mine where storm runoff was dramatically flashy and potentially problematic, site TP-3 (Fig. 9). To assess the extent of contaminant loading during storm runoff at this site, we set up an ISCO automated sampler at the weir location prior to a predicted deluge (Fig. 10). We could have connected the ISCO directly to the Campbell data logger on site and triggered sampling based on changes in the stage. However, because we already knew how this stream responded to heavy rain, we simply connected an ISCO tipping bucket rain gauge to the sampler and programmed the sampler to initiate sampling runoff at 15-min intervals as soon as intense rainfall started. This worked very well, as we were able to collect samples during the rising limb, peak and most of the recession of the hydrograph.

Figure 10. The compound weir below the "TP-3" waste piles, Elizabeth Mine, South Strafford, VT, prior to (top) and during (bottom) a storm event. We programmed an ISCO automated water sampler with a tipping bucket rain gauge (not shown) to sample at the commencement of intense rainfall.

## Conclusions

Appropriate remediation and restoration of abandoned mine lands requires runoff and contaminant loading data for the targeted remediation sites. The sampling and analysis that the remediation engineer hopes for is often prohibitively expensive. This study provides relatively inexpensive methods of data collection, using mostly off-the-shelf, battery-operated devices that provide a large amount of useful data.

Contaminant loading from AMD sites is a critical factor in remediation design. To calculate loading, one must know both the discharge and the contaminant concentrations. For discharge, we installed relatively inexpensive flow devices such as thin-plate weirs and Parshall flumes at our sites, and we monitored stage with Druck transducers connected to Campbell data loggers. This equipment has been highly reliable at most sites, with little drift in pressure values between calibrations of the Druck depth-level transducers. At sites where near real-time data are necessary, or in cases where clients request the ability to monitor flow from a remote location, we use a combination of 5-watt VHF radios linked to a 3-watt cellular phone to aggregate the data from our Campbell data loggers and transmit those data to a modem-equipped computer in our office, which then automatically uploads to an online database accessed by a web site.

The other critical variable required to calculate metal loads is contaminant concentrations, which can be prohibitively expensive to determine on a regular basis. We focused our water sample collection on times when profound changes in the hydrograph were anticipated so that we could assess a worst-case loading scenario. We used ISCO automated samplers to collect samples at pre-programmed intervals during the rising limb, peak, and recession of the hydrograph, thus allowing us to accurately determine the total load during peak or pulse events. In addition, we were able to correlate specific conductance to metals concentrations at the weir location, thus providing a very inexpensive, yet relatively accurate loading estimate based on regularly-collected pH, conductance, and water temperature data acquired with self-logging, in situ Hydrolab data sondes.

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