BLM

Microclimate Effects from Closing Abandoned Mines with Culvert Bat Gates

Technical Note 416

March 2005

Cover photo: A Townsend's big-eared bat, which is a special status bat species. Photo courtesy of Kirk Navo, Colorado Division of Wildlife.

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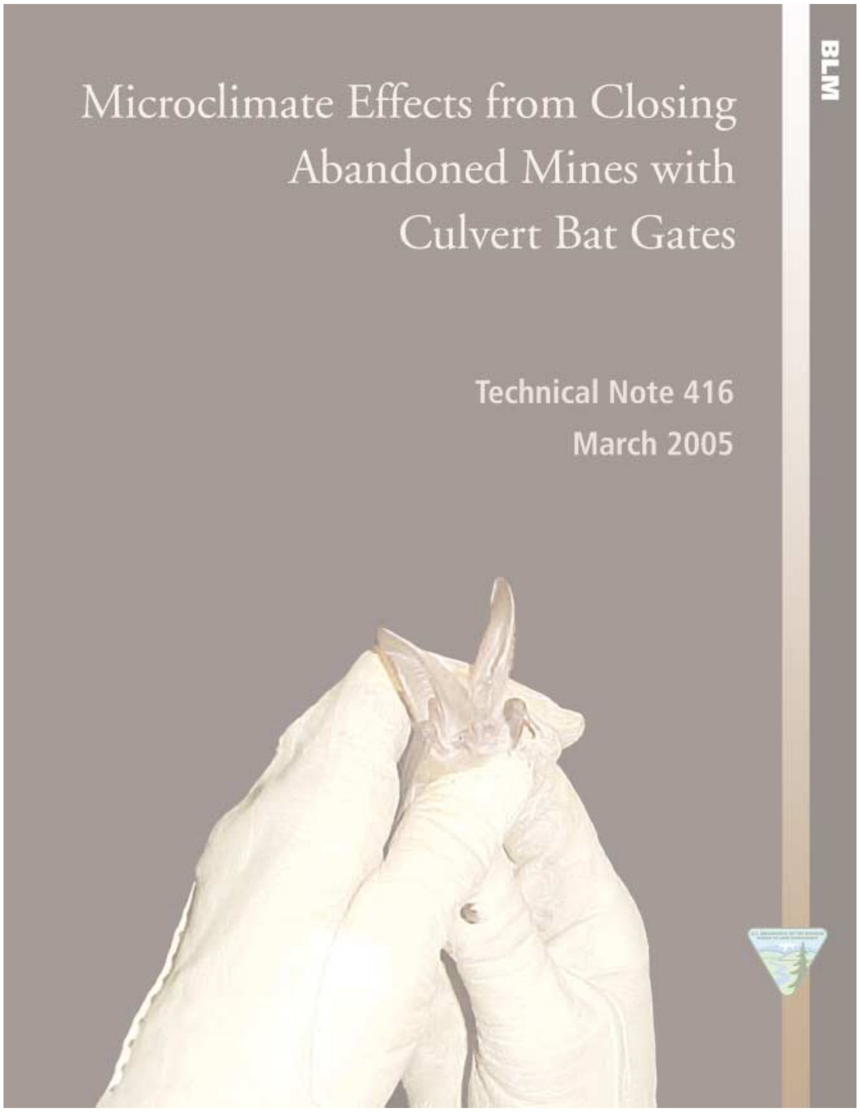

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Contents

Abstract

Numerous bat species, including some threatened species, inhabit thousands of abandoned mines across the United States. Some of their bat habitat has been lost as mines are closed to reduce hazards to the public. Bat gates have been used to close some mines because they restrict public access while still allowing the bats to fly in and out. However, they are not appropriate for mines with trench portals. The Bureau of Land Management (BLM) proposed using culverts in the trenches and closing the culverts with bat gates. BLM worked with the Colorado School of Mines (CSM) to study the effects of this type of closure on the microclimate of the mines, which in turn could affect bats' fidelity to the habitat. CSM developed a process that integrated continuous climate measurements with data from a computer model and tested it at three abandoned uranium mines in southwestern Colorado. Measurements were taken for 1 year prior to and 1 year after closing the mines with culvert gates. The results showed that the culvert gate closure slightly modified the microclimate by essentially extending the length of the mine, but indicated that bats should be able to locate the same climatic conditions a few feet away from their original roosting locations. The computer model predictions compared favorably with the measurements, and the model provided relevant insight regarding the qualitative trends reflected by the field measurements.

Introduction

There are over 300,000 abandoned underground mines in the United States, many of which provide important habitat for a variety of bat species. Currently, the mines are being closed to reduce hazards to the general public. Approximately 33,000 abandoned mines have been closed in the United States thus far and, of these, about 1,200 have been closed with special gates to preserve bat roosting habitat (Meier and Garcia 2000). These gates allow bats to pass in and out of the mines, while keeping the public out (Figure 1).

Some abandoned mines have an open trench that declines below the ground surface to the mine portal (Figure 2). These trenches typically are 10 to 20 meters (33 to 66 feet) long, declining into the ground at 6 to 10 degrees. At the bottom end of the trench, the mine portals vary in cross section from 1.2 meters (4 feet) wide by 1.8 meters (6 feet) high up to 6 meters (20 feet) wide by 2.4 meters (8 feet) high. Generally, the trenches are too large to cover effectively with grating and bat gates and are backfilled. However, backfilling is a poor solution when it is important to maintain habitat for bats, particularly special status bat species.

Figure 1. A typical bat gate.

Figure 2. A typical trench portal leading to a uranium mine in western Colorado.

In an attempt to preserve bat habitat on public lands, the Bureau of Land Management (BLM) proposed using culvert gates for the trench mine openings (Figure 3). With this method, a culvert is placed in the trench from the surface so that it extends part-way into the mine portal. A bat gate is welded onto the surface end of the culvert. Finally, the trench is backfilled, covering the original mine portal and culvert, with the exception of the gated end. However, the effect of culvert gates on the microclimate of the mine, and consequently on bats' fidelity to the mine habitat, was unknown. Microclimate variations are critical since temperature changes of only a few degrees may cause bats to abandon maternity and hibernation roosts (Tuttle and Taylor 1994).

Figure 3. A culvert gate prior to backfilling the trench.

Bat habitat in abandoned mines and caves was lost when the surface openings were restricted in a number of cases (Tuttle and Taylor 1994). Most of these restrictions were more severe than culvert gate closures. Other reports have hypothesized about the causes of such habitat losses (Tuttle and Stevenson 1978). To determine whether the culvert gate closures would significantly impact bat habitat, BLM selected three mines with trench portals for study. They are designated as mines 31, 59, and 65 and are located on Calamity Mesa, southwest of the town of Grand Junction, Colorado (Figure 4). The mines are less than 30 meters (98 feet) deep and are excavated in the sandstone of the Salt Wash Member of the Jurassic Morrison Formation.

For this study, biologists from the Colorado Division of Wildlife surveyed the mines and confirmed bat habitation. An expert in mine safety from the National Park Service assessed mine safety conditions and mapped the layout of the mines. Then mine ventilation experts from the Colorado School of Mines (CSM) evaluated the effect of culvert gates on the mine microclimates. They developed a process that involved integrating measurements of temperature, humidity, airflow, and radiation from the mines with data from a computer model.

This study was the first attempt to scientifically evaluate underground climate changes from restricting airflow with culvert gates. The results of the study are summarized in this Technical Note. Detailed results of CSM's research are available online at *www.blm.gov/aml/amldocs/CulvertGateFinalReport.pdf* or from the abandoned mine lands coordinator at BLM's Colorado State Office.

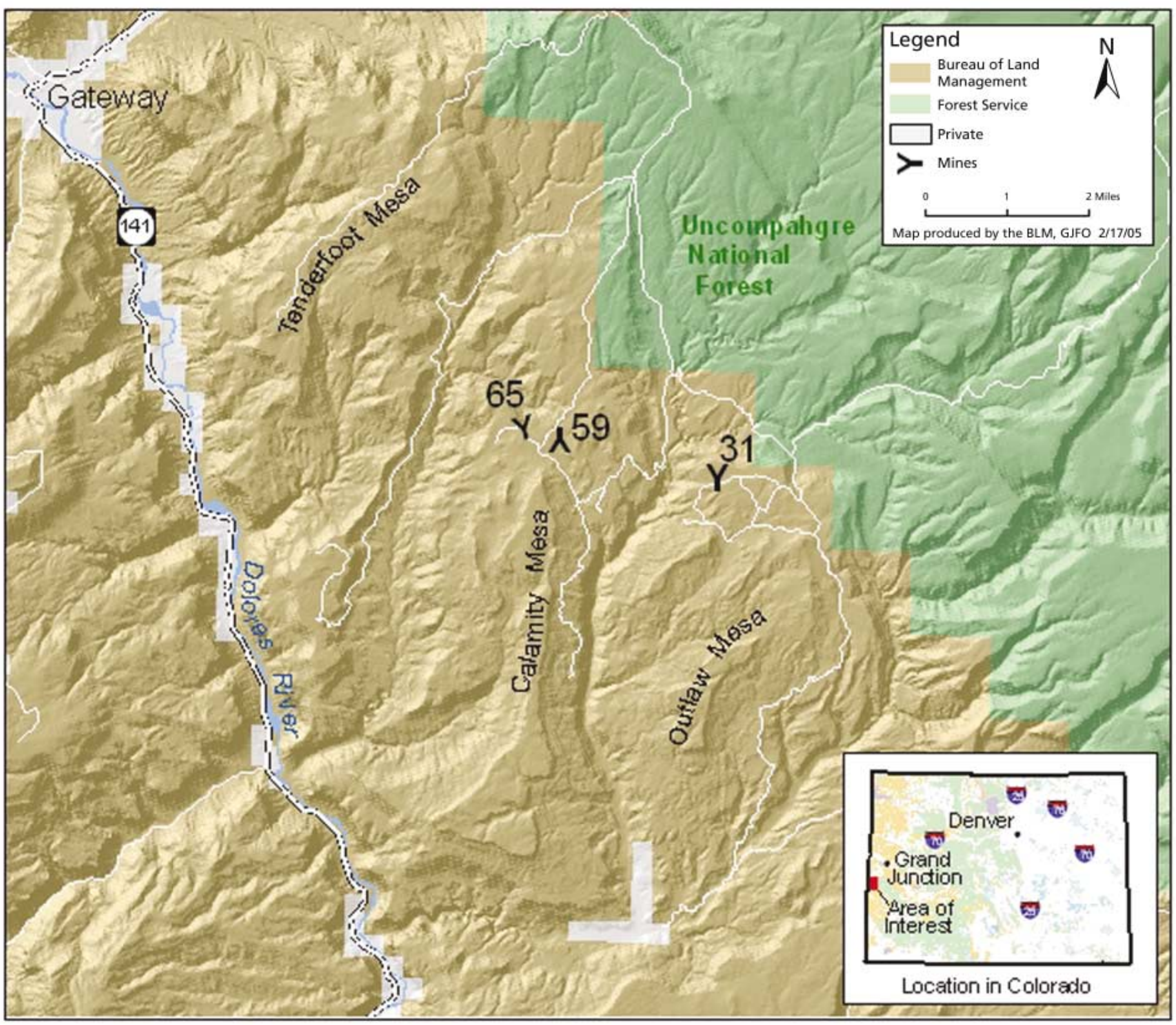

Figure 4. Location of study mines.

Climate Measurement

Method

The microclimate in a mine varies temporally and spatially because of complex interactions among the surface climate, rock temperature, and mine airflow, humidity, and geometry. For this study, the temporal data was measured continuously with miniature data loggers at a number of critical locations throughout the mines and on the surface. Measurements were taken from September 1998 to November 2000, approximately 1 year prior to and 1 year after closing the mines with culvert gates. Measurement points were located near the underground air/rock interface as well as in the center of mine passages. Obtaining measurements was challenging because the instruments were subject to vandalism and removal prior to closure of the mines. Those that didn't have armored cables were susceptible to rodent damage. In addition, all of the instruments had to be powered with long-lasting batteries, as access was impossible in winter and difficult, expensive, and hazardous at other times.

Surface temperature fluctuations create thermal gradients in abandoned mines resulting in a nonuniform air density distribution. Under the action of gravity, this nonuniform air density induces airflow called natural convection. Though active mines have fans that produce large volumes of airflow, the study mines have low airflow rates, around 0.05 meters per second (0.16 feet per second). Reasonably priced commercial devices cannot measure air velocity lower than about 0.3 meters per second (1 foot per second), and they are too fragile to deploy for long periods in an abandoned mine. CSM developed a $300 ultrasonic transducer that measured air velocities ranging from 0–0.06 meters per second (0–0.2 feet per second), with a small number of readings above 0.12 meters per second (0.4 feet per second) in the study mines. This velocity range compares with measurements of 0.05–0.25 meters per second (0.16–0.82 feet per second) from smoke tubes, in which smoke is used as a tracer for slow-moving air, and model predictions of about 0.06 meters per second (0.2 feet per second).

The study mines are abandoned uranium mines that contain radiation. An instant working level and gamma meter (provided by the National Park Service) measured discrete radiation ranging from 0.94 to 11.84 working levels [1] during two mine visits. In addition, dosimeters measured accumulated exposure from combined x-ray, beta, and gamma radiation, and alpha cups measured alpha radiation. Currently, it is assumed that the relatively short-lived bats are not impacted by radiation and no radiation effects have been observed by CDOW. Nevertheless, the data gathered at the study mines could be useful for much-needed future research on radiation effects on bats.

Results

When examining temperature and humidity data over the period of the study, it was only necessary to differentiate between the changes caused by the culvert gate closure and those caused by surface climate variations because the rock mass and the mine geometry did not change during the study. To isolate the culvert gate impacts, CSM had to locate data for short periods when the surface climate was approximately the same before and after mine closure.

[1] A working level is a concentration of radon daughters that will deliver 1.3×10^5 MeV of alpha energy per liter of air. At equilibrium, 1 WL = 100 pCi/l.

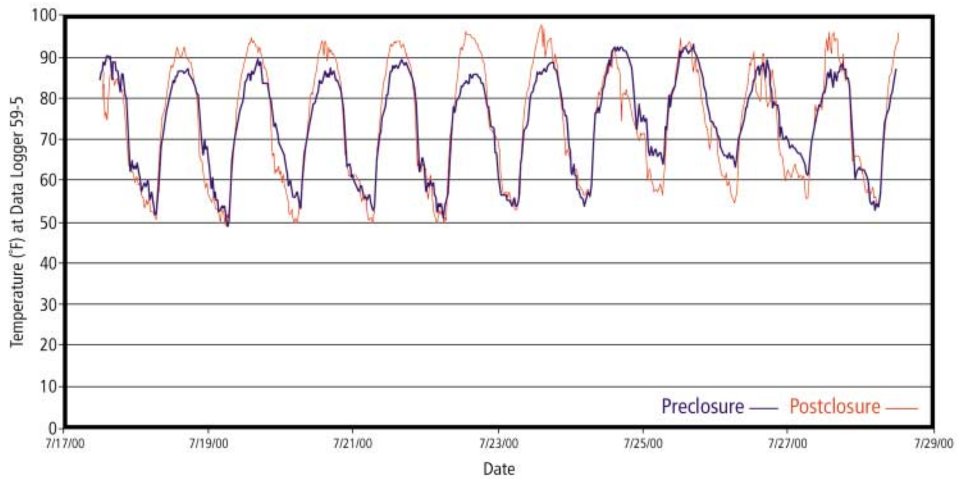

Figure 5. Pre- and postclosure surface temperature for a subset of the data with similar surface conditions.

CSM found one 600-sample subset of postclosure data for 11 days in July that was similar to an equal-sized subset of the preclosure data (Figure 5). (Preclosure dates were shifted to match postclosure dates so data for both subsets could be plotted on the same graph.) Mean temperature increased by 0.3 to 1.9 Kelvin (0.6 to 3.4 °F) from the preclosure climate for all but 2 of the 11 data loggers in the 3 study mines.[2] The pre- and postclosure data subsets, while similar, were not exactly the same. The surface temperature of 295 Kelvin (71 °F) at the beginning of the preclosure data window was lower than the surface temperature of 296 Kelvin (73 °F) at the beginning of the postclosure data window. Since air movement in the study mines was minimal, the in-mine air temperatures were strongly affected by preclosure conditions. Therefore, the pre- and postclosure temperature difference is probably caused by climate, not the culvert gate closures.

In the winter, much of the surface data was lost due to instrument failure, so definitive in-mine climate analysis was not possible. Nevertheless, the in-mine climate measurements seemed to be less variable in winter than in summer in both pre- and postclosure periods. In addition, the in-mine temperatures seemed to increase slightly after closing the mine with culvert gates.

Closure reduced the temperature variance at every data logger and the variance decreased as distance from the portal increased (Figure 6). Since the surface temperature was warmer than the mine

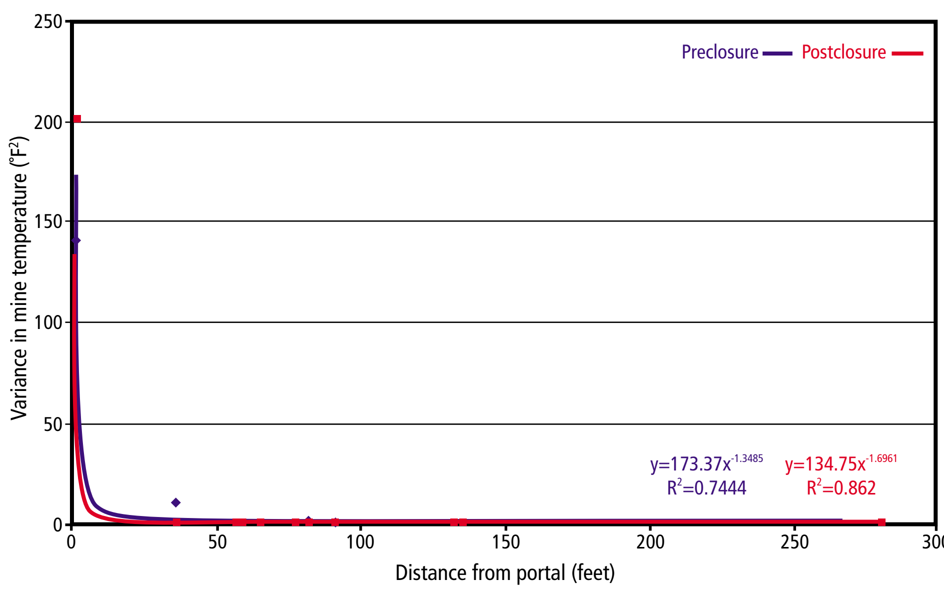

Figure 6. Pre- and postclosure variance in temperature versus distance from the portal.

[2] The measurement error was +/– 0.4 to 0.7 Kelvin.

temperature during these periods (summer months), the air was more affected by conduction from the surrounding rock than by convection from the surface except close to the portal (Figure 7).

This declining climate variance with distance into the mine leads to the conclusion that culvert gate closures have the same effect on the microclimate as if the mine were simply lengthened. Reduced variance, or attenuation, is caused by thermal inertia; i.e., the effect of the surrounding rock mass and delayed reaction to changes in the surface temperature. Surface climate changes are not immediately felt in a mine, and they have a reduced effect with mine depth. Consequently, a mine may not react completely to a surface temperature rise or fall before the surface temperature trends in the opposite direction. Of course, the mine microclimate reacts more quickly to surface climate changes when the temperature difference between surface and mine air increases, causing stronger convection airflows.

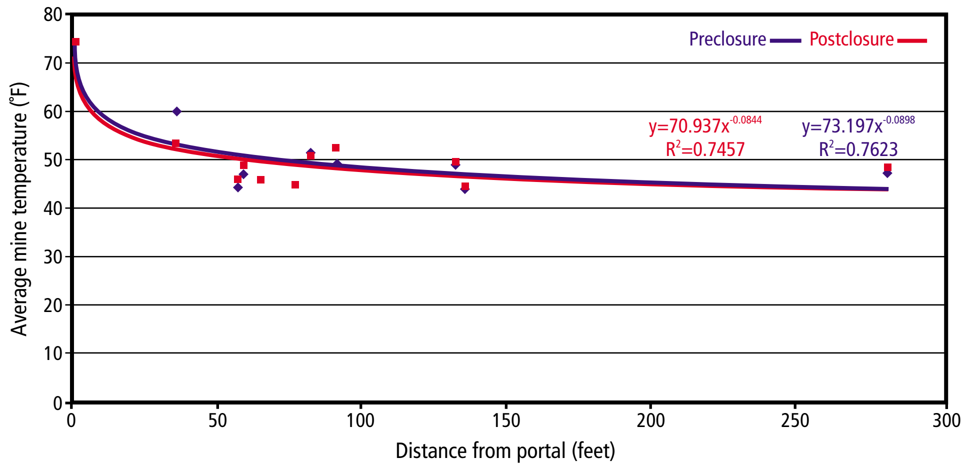

Figure 7. Pre- and postclosure mean temperature versus distance from the portal in summer.

Computer Modeling

Method

Commercially available software, CFD-ACE (CFD Research Corporation, Huntsville, Alabama), was used to numerically solve coupled, nonlinear, second-order partial differential Navier-Stokes equations that represent the natural convection airflow (Dodds 2001). The following assumptions and simplifications were made in developing a model for this application:

- **Mine Geometry** – The model assumes that the mine has a simple in-line opening that declines 6 degrees and dead-ends (Figure 8). The back of the original mine portal is 2 meters (6.6 feet) below the ground surface. This geometry is the same as the simplest of the three study mines. It is also the most restrictive for airflow and therefore is most impacted by any changes, such as installation of a culvert gate closure. Other geometries, such as numerous mine openings and underground workings, offer less resistance to airflow and therefore less change in mine air temperatures from any restrictions on airflow. The model also assumes there are no changes in the mine cross section and that the mine has smooth walls. These variables are relevant in mine ventilation, but they are second-order effects compared to the nonalignment of the mine opening and the acceleration of gravity. These simplifications and assumptions reduce the model to a two-dimensional, planar slice of the mine. They significantly reduce the computational effort, while capturing the salient physical mechanisms.

- **Rock Temperature** – Mine air temperatures are affected by heat conduction from the surrounding rock mass. The model assumes that the rock temperature is constant and equal to the mean annual surface temperature, which is about 284 Kelvin (52 °F) at approximately 1.83 meters (6 feet) into the rock mass. This rock temperature is a rule of thumb for shallow mines. Generally, rock temperatures do increase with depth by about 0.5 Kelvin (1 °F) per 30 meters (98 feet); however, the study mines are too shallow for this effect.

Results

The surface and in-mine temperature and airflow data collected helped calibrate and verify the computer model of the natural convection airflow in the mines.

The computer model predicted two convection cells that were previously unreported. One cell is near the mine portal and the other is throughout the remainder of the mine (Figure 9). In-mine climate measurements support the two-cell model prediction, as pre- and postclosure average temperatures are

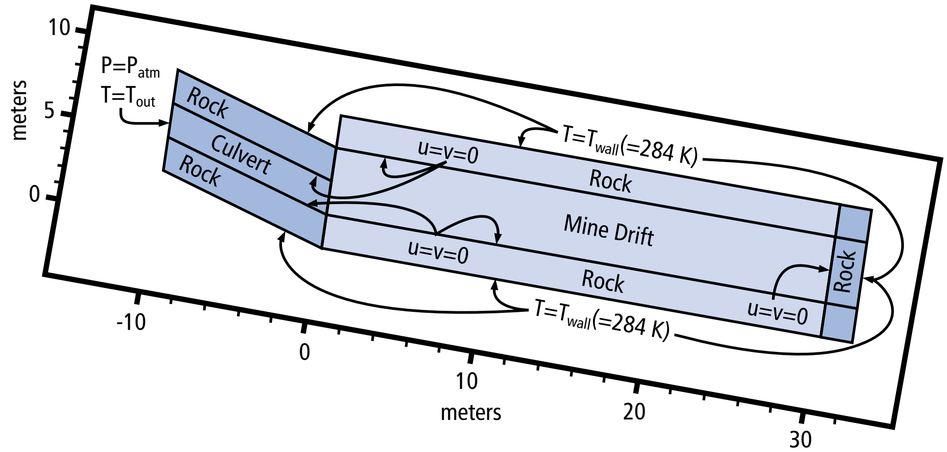

Figure 8. Vertical cross section of CFD model mine with typical boundary conditions.

higher in the cell near the mine portal than they are in the rest of the mine (Figure 7). Furthermore, temperature variance is much greater in the cell near the mine portal (Figure 6).

The model responded to changes in surface temperatures and showed that, characteristically, it should take about 1 hour for a change in outside temperature to completely take effect inside the mine, dependent upon the location and magnitude of the temperature change. Actual changes took about 2 hours. The model results attenuate with depth into the mine, similar to the in-mine climate measurements. The in-mine climate data show that when surface temperature fluctuates about 12 Kelvin (22 °F), mine temperatures fluctuate about half as much. Actual attenuation within the test mines was more dramatic than in the model mine.

The researchers varied the computer model to study the effects of several scenarios that would have been costly to test in the field:

- The first change to the model was to add a culvert gate onto the original mine portal, where the culvert is 10 meters (33 feet) long, 4 meters (13 feet) in diameter, and laid in the trench bottom at a 6-degree incline. The surface end of the culvert became the new mine portal. The microclimate temperature profile and two convection cells did not change in shape, and the portal cell remained close to the new portal (compare Figures 9 and 10).

- The next change was to increase the culvert inclination to 27 degrees. The temperature profile

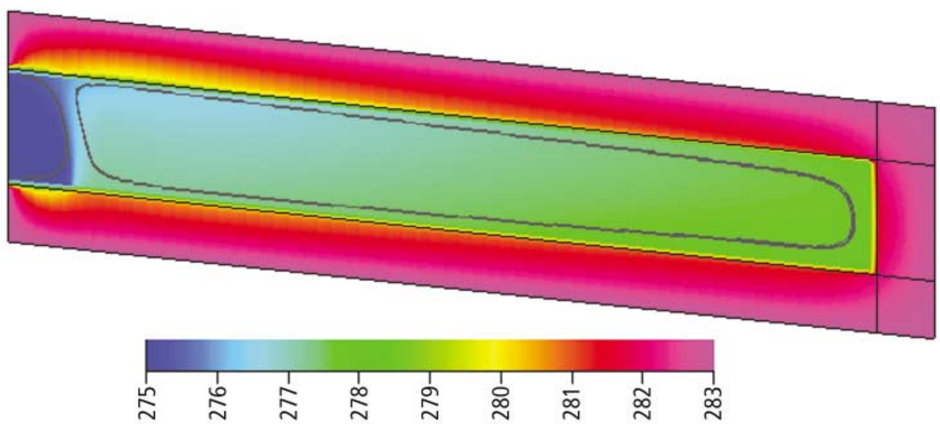

Figure 9. Simulated mine temperature (Kelvin) profile.

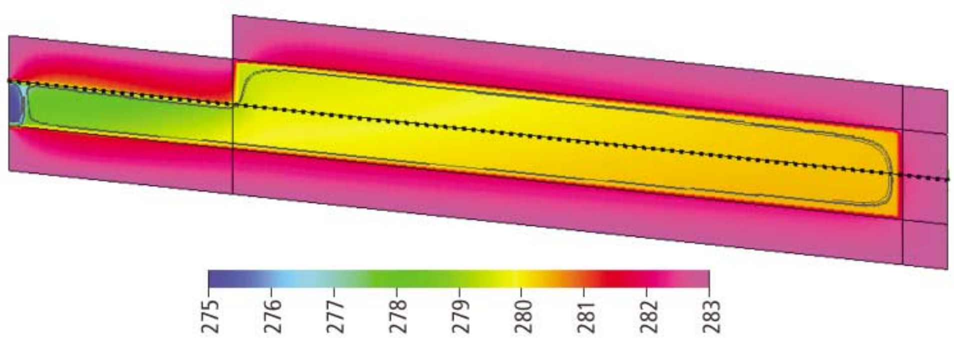

Figure 10. Simulated mine temperature (Kelvin) profile with culvert.

and convection cells were similar in shape and magnitude to the 6-degree culvert model (Figure 11).

The model did not simulate all of the complexities inherent to a real mine. Real mine openings are three-dimensional, have rough rock surfaces, contain turns and bends, have variable dimensions, and contain abrupt changes in perimeters caused by roof falls.

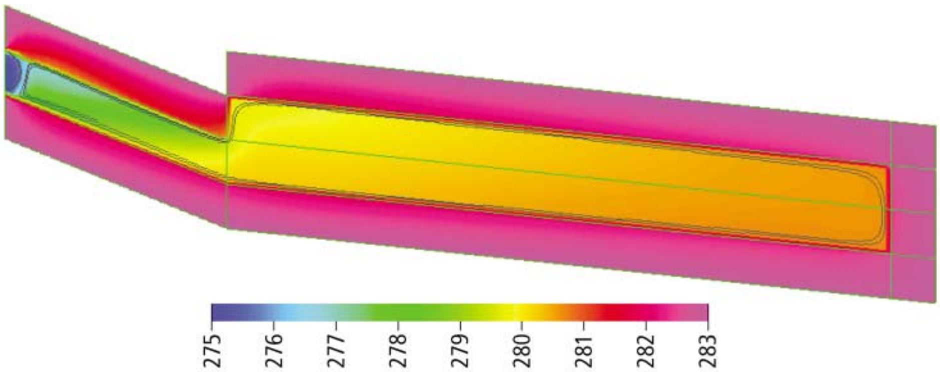

Figure 11. Simulated mine temperature (Kelvin) profile with culvert at steep angle.

Conclusions

Abandoned mines with trench portal type openings pose a special challenge for land managers who are trying to preserve ecosystems by maintaining habitat for a diverse set of bat species. This study found that using the culvert gate technique for closing these mines resulted in only small temperature changes on the order of 1–2 Kelvin (2–4 °F), with a measurement error of +/– 0.4 to 0.7 Kelvin. The increased temperatures occurred during the summer maternity roosting season, so even though the increases were small, they could be beneficial to the bats. Although the study was not conclusive, it indicated there was also little in-mine temperature change from the culvert gate closure in winter.

While bats may be sensitive to these small temperature changes, they do not have to vacate the habitat. Guano spots in the mines studied indicated bats were not congregated at either the portal or the end of the mine. Any roosting bats would experience similar or greater temperature ranges on a frequent basis. The changes are small enough that bats can easily find roosts slightly deeper in a mine or toward the portal where the temperature regime is the same as before. Based on these results, CSM found no reason for managers to discontinue the use of culvert gates, especially if the alternative is to backfill the mines and eliminate the habitat. Though a culvert gate backfill is more expensive (about $3,000 per opening) than a simple bat gate (about $1,000 per opening), which is an important consideration when closing thousands of mines, small-diameter culverts installed at a high angle can minimize costs.

CDOW surveys indicated reduced bat activity in the mines in the first season after closure with culvert gates (Navo et al. 2000). The reduced activity might not be the result of microclimate changes from adding the culvert gates; it could instead be the result of frequent visits by researchers, instrumentation installed in the mines, closure activity by construction contractors, increased recreational activity in the area, or surface climatic changes. CSM recommends that bat surveys continue and that other causes for the reduced bat activity be investigated. CSM also recommends that new mines be identified for additional pre- and postclosure monitoring and computer modeling. Future models should study more extensive mine complexes, more closely evaluate effects of actual conditions, and analyze detailed features of bat gate designs.

The model of airflow and heat transfer in mines developed by CSM can be used by land managers to predict the effects of modifications to caves and mines. While the model requires further development and modifications for specific sites, using it is more cost-effective than conducting physical experiments in the field. Combining model analysis with baseline monitoring and analysis of temperature, humidity, and airflow gives land managers a comprehensive procedure to assess the effect of remedial actions on cave and abandoned mine microclimates and avoid any future unintended loss of bat habitat.

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