

Environmental Change at Kartchner Caverns: Trying to Separate Natural and Anthropogenic Changes

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Abstract—Cave temperature and moisture levels are important factors in the environmental health of Kartchner Caverns. Monitoring indicates the cave has warmed and moisture levels have fallen over the past 14 years. Timing and patterns of change within the cave suggest that changes are due to development as a show cave. However, changes in other caves, surface temperature and precipitation, and in shallow local aquifers suggest that cave changes relate to regional patterns. Changes at Kartchner Caverns represent a combination of anthropogenic and regional natural causes. Separating these different factors is an important on-going goal in protecting the cave.

Kartchner Caverns State Park (KCSP) is a show cave in southeastern Arizona. The cave was discovered in 1974 and became a State Park in 1988 (Tufts and Tenen 1999). After pre-development studies to assess the condition of the cave, to establish baseline data, and to determine how best to develop the cave, Arizona State Parks began development of the cave for ecological education and tourism. The development included creating tunnel entrances to the cave, building trails for tours, and installing a lighting system. In November 1999 tours began in the Rotunda-Throne Room section of the cave. Development of the Big Room section of the cave continued until November 2003 when it opened. Since 1999 approximately 750,000 people have toured the cave. One of the primary goals during the development of Kartchner Caverns was to develop it in as ecologically sensitive manner as possible (Travous and Ream 2001).

Caves often house extremely sensitive ecosystems. Small changes in the temperature, humidity, water quality, nutrient inputs, or other environmental parameters can lead to major, potentially detrimental, changes to how a cave functions. Kartchner Caverns is a wet cave with dripping and pooling water, periodic flooding, and high ambient humidity. This water is crucial to maintaining the cave environment, the growth and appearance of cave formations, and possibly the vitality of the *Myotis velifer* maternity colony in the cave. In an arid environment, such as the one in which Kartchner Caverns occurs, caves can be especially sensitive to environmental changes. If development of Kartchner Caverns caused a significant increase in the exchange of cave air and the outside air, the cave could dry out. Because of concern for this possibility, the cave microclimate was studied prior to development (Arizona Conservation Projects, Inc., 1991; Buecher 1999) and has been monitored through development and operation (Toomey 2003). A variety of cave microclimate parameters have been studied at Kartchner Caverns. This paper will focus on cave air temperature and relative humidity data collected at Kartchner Caverns. These parameters have been consistently monitored, are available for several caves near Kartchner Caverns, and are relatively easily interpreted.

The primary long-term temperature and humidity data from the cave come from Environmental Monitoring Stations (EMS) within the cave (figure 1). These are locations at which air, water, and soil temperature, relative humidity, and pan evaporation are measured manually on a periodic basis, usually weekly or monthly. Temperatures are measured with small, digital probe thermometers; relative humidity is measured using a digital probe thermometer equipped as a sling psychrometer. During pre-development studies Arizona Conservation Projects, Inc., personnel took measurements; since those studies ended, Arizona State Parks personnel have continued to monitor these stations. The EMS dataset is the most complete microclimate dataset for the cave. In addition, the temperature readings from these stations are all calibrated against a single master mercury thermometer that has been used since the beginning of Kartchner Caverns studies. The use of this calibrated dataset eliminates problems from varying instruments and instrument drift.

Measurements from the stations show that the cave has warmed and dried since monitoring began in 1989. The largest change is found at stations in the Rotunda-Throne area of the cave such as the Lower Throne EMS (figure 2). The data from Lower Throne shows an approximately 4 °F rise in temperature between the beginning of 1997 and the present. The temperature rise peaked with a running mean of approximately 71.9 °F early in the summer of 2004. This temperature is approximately 4.5 °F degrees warmer than the pre-development levels in the same area. However, the trend has reversed slightly since that peak and the mean temperature at the station is now around 71.6 °F. Accompanying the temperature increase at this station is a decrease in humidity. Between 1989 and the end of 1996 the humidity at the station had a mean of 99.43% (standard deviation 0.71%). For the period from the beginning of 1997 through early 2004, the humidity at the station was generally lower and more variable (mean 97.45%, standard deviation 1.32%). The difference in the humidity between two periods (1989-1996 and 1997-2004) is highly significant statistically (unpaired, one-tailed, heteroscedastic, t-test probability $P < 0.00001$).

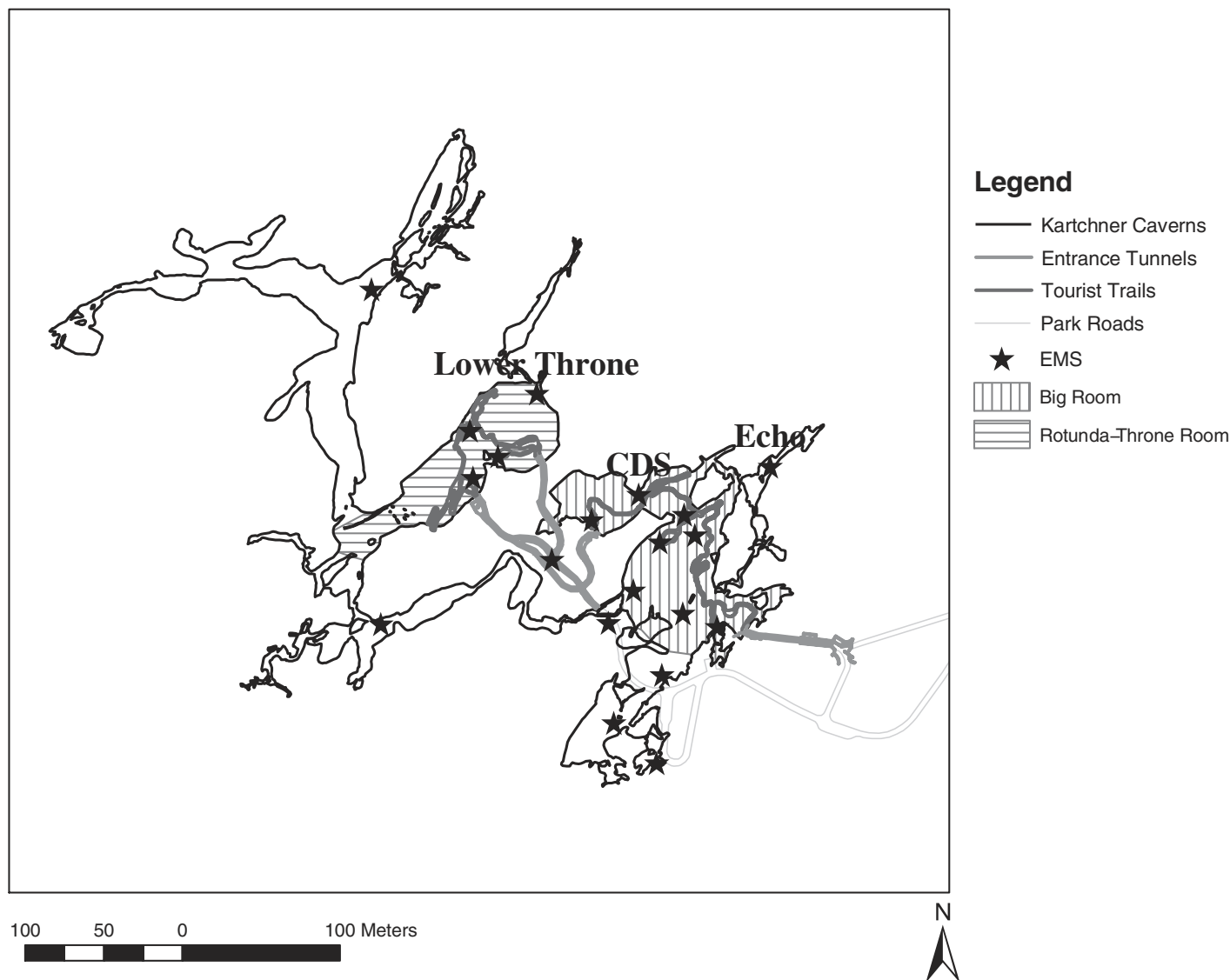


Figure 1—The location of Environmental Monitoring Stations for cave microclimate in Kartchner Caverns. Three stations are labeled with their names: Lower Throne, Echo, and Cul De Sac (CDS).

These data and those from other stations indicate recordable and statistically significant climate change in portions of the cave that coincide with the show cave development and cave tour operations. At this point, data from the most developed and high-traffic areas demonstrate larger changes than data from areas peripheral to human use (figure 3). However, at least some change is evident in all monitored areas of the cave. For the continued management of the cave, understanding the source of the observed temperature and humidity changes is vital.

Two basic classes of mechanisms (or a combination of them) may be responsible for the changes observed in the cave. The first class would be anthropogenic (human generated) causes related to the development of the cave. This class would include various factors that increase the amount of energy in the cave and thus raise the temperature and increase evaporation of available water. Among these factors would be metabolic heat generated by humans while in the cave, heat from the lighting systems used in the cave, and heat from the hydration of concrete. Anthropogenic causes could also include changes

that affect the airflow in the cave to either increase temperature or allow the loss of moisture. This could include leaking of air through airlocks and tunnels.

The second class of mechanisms would be local, regional, or larger scale natural factors, changes, and trends that may be reflected in the microclimate of the cave. These factors, changes, and trends may include regional warming and major droughts.

Identifying the influence of each class of mechanisms at Kartchner Caverns is important for understanding the changes and to determine future courses of action. Several approaches to data analysis can be combined to help determine whether regional climate change, anthropogenic changes related to development, or both are responsible for the changes in temperature and moisture.

The first approach is to examine patterns within the Kartchner Caverns data to see if they are consistent with any one cause. Using this approach alone suggests that development is overwhelmingly the cause of the observed changes.

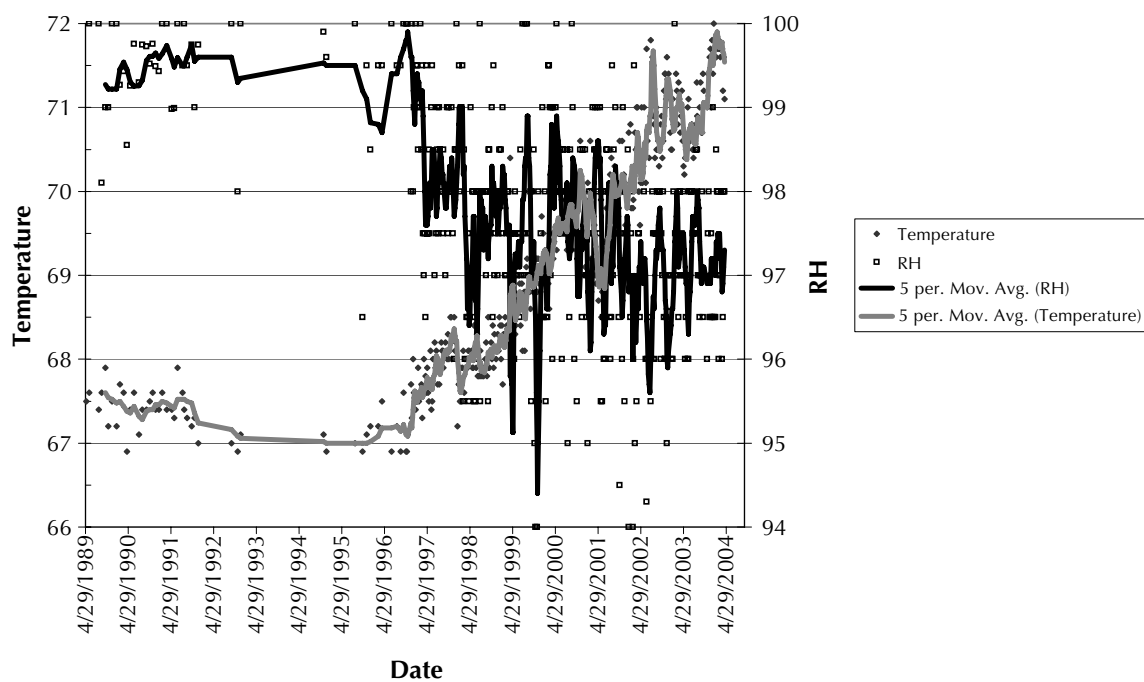


Figure 2—Air temperature and relative humidity as measured at the Lower Throne Environmental Monitoring Station. Points are individual weekly measurements. The lines show five-measurement moving averages.

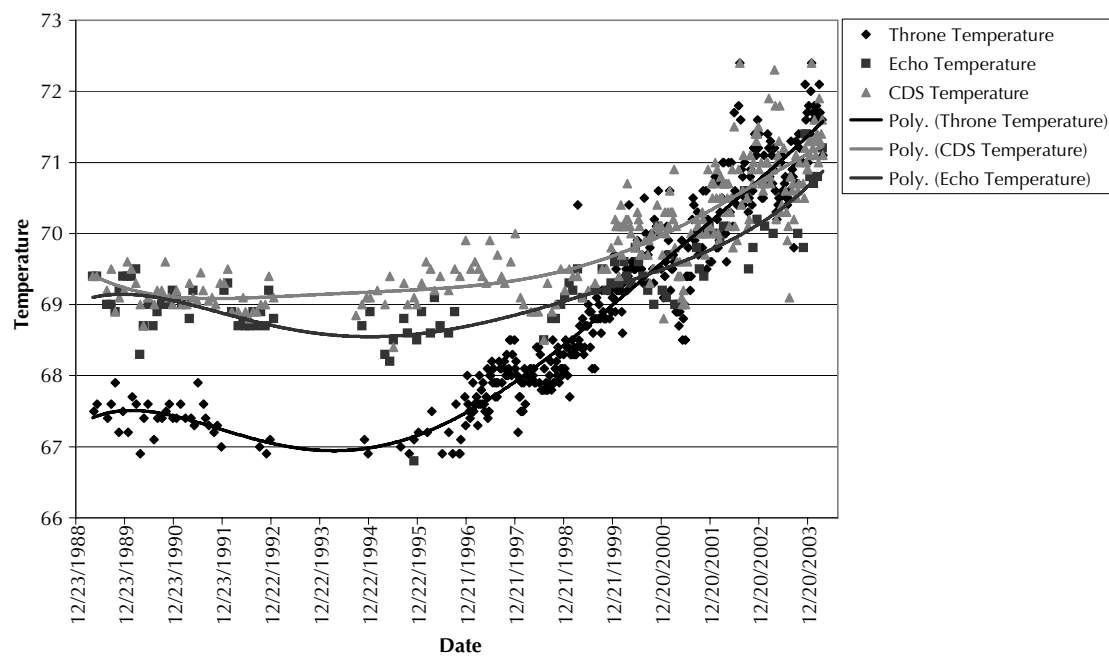


Figure 3—Temperature change at three Kartchner Caverns Environmental Monitoring Stations. The Throne station is in the Rotunda-Throne section, which has been toured since 1999. The CDS station is near the Big Room tour route, along which tours began in 2003. The Echo station is off the tour routes in an undeveloped section of the Big Room. Note the differences in the amount and timing of warming in the different areas.

The timing of the changes corresponds with the timeframe of development. That is, the changes seem to start at about the same time the tunnels were completed and subsequent development ramped up (figure 2 and 3). In addition, the pattern of change, with larger amounts of change in more developed areas, also supports the conclusion that the observed changes are related to development (figure 3). Toomey (2002) basically came to this conclusion.

However, if we also compare the data from Kartchner to a larger regional dataset and to other lines of evidence, the conclusion is a bit more complicated than presented in Toomey (2002). A small regional dataset of temperature measurements from four caves and humidity measurements of two of them provides some comparison data. In addition, water levels from four wells near Kartchner Caverns and the temperature data from the KCSP weather station also provide useful information. These datasets indicate that at least some (perhaps most) of the climate change observed in the Kartchner Caverns record is probably related to regional climate patterns.

Jerry Trout (National Cave Program Manager, USDA Forest Service) provided temperature and humidity data from four caves on the Coronado National Forest, southeastern Arizona. These caves are Whetstone Cake Cave #1, Whetstone Cake Cave #2, SP Cave, and Cave Mine Cave, which are all located within 35 miles of Kartchner Caverns. Whetstone Cake Cave #1 and #2 are small caves (300-450 feet long) with relatively large entrances in the Whetstone Mountains above Kartchner Caverns State Park. Although they are not particularly good analogues to Kartchner Caverns, because their small size and

large entrances result in large seasonal differences in temperature, they do provide data from undeveloped caves that are quite near the park. Cave Mine Cave and especially SP Cave are much better analogues for Kartchner Caverns. Each is a relatively extensive, undeveloped cave. They are located in the Huachuca Mountains near Sierra Vista.

The Forest Service has been collecting limited data on these four caves for approximately 13 years. This data consists of quarterly to semiannual temperature readings in each cave. In addition, relative humidity was measured in both Cave Mine Cave and SP Cave quarterly to semiannually. These data were not all taken by the same people or with the same instruments. However, the data comprise the best long-term cave data for comparison with the Kartchner Caverns data.

The data from the two Whetstone Mountains caves demonstrates a warming trend over the past 13 years. The mean annual temperature for each has warmed between 3 and 4 °F between 1991 and 2002 (figure 4). The data from the Huachuca Mountains caves also show warming over the past 15 years (figure 4). SP Cave shows about 2 °F warming, and Cave Mine Cave shows about 1.5 °F. The warming in these four undeveloped caves is similar to that seen in Kartchner Caverns.

Like the temperature record, the relative humidity records from SP Cave and Cave Mine Cave indicate that some undeveloped caves in the region show climate change similar to that seen at Kartchner Caverns (figure 5). Since 1990, the humidity measured in SP Cave has decreased to a similar degree as that measured in the Echo Passage. The humidity in Cave Mine

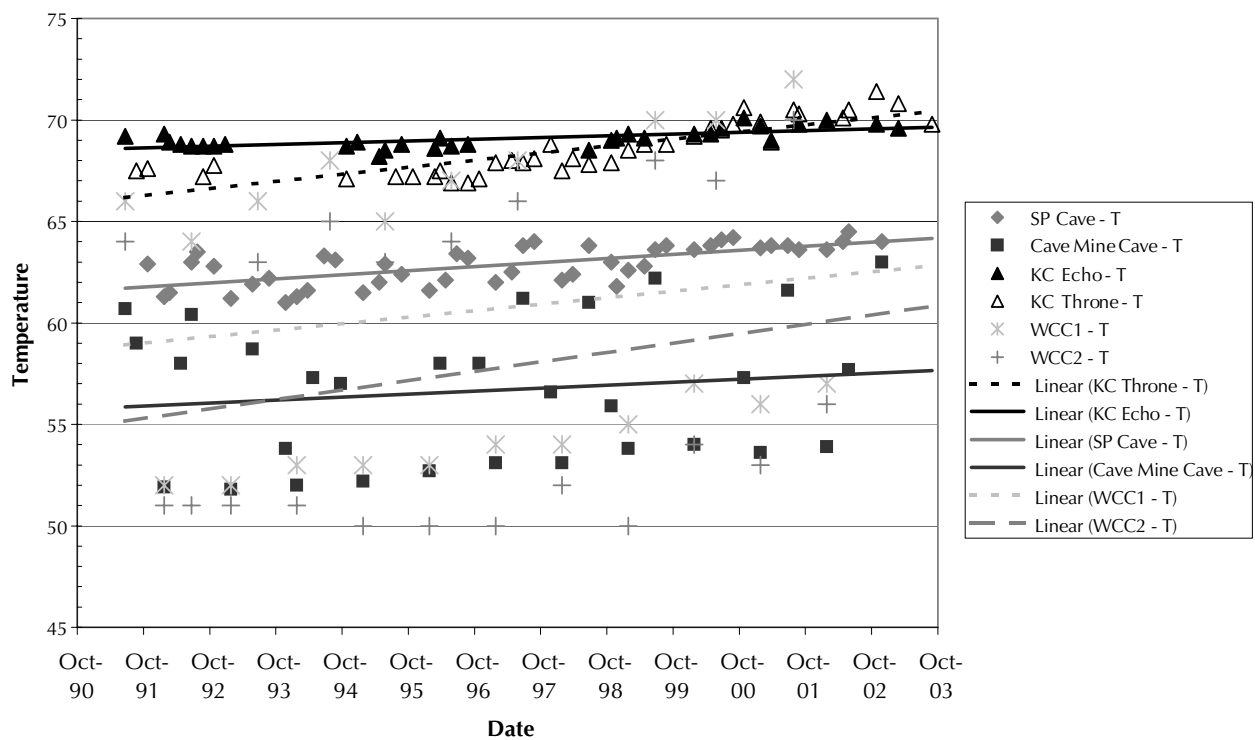


Figure 4—Temperature (and linear least squares best-fit lines for the temperature) of SP Cave (Huachuca Mountains), Cave Mine Cave (Huachuca Mountains), Whetstone Cake Cave 1—WCC1 (Whetstone Mountains), and Whetstone Cake Cave 2—WCC2 (Whetstone Mountains). A portion of the temperature data from the Echo Passage EMS and Lower Throne EMS at Kartchner Caverns is also shown for comparison.

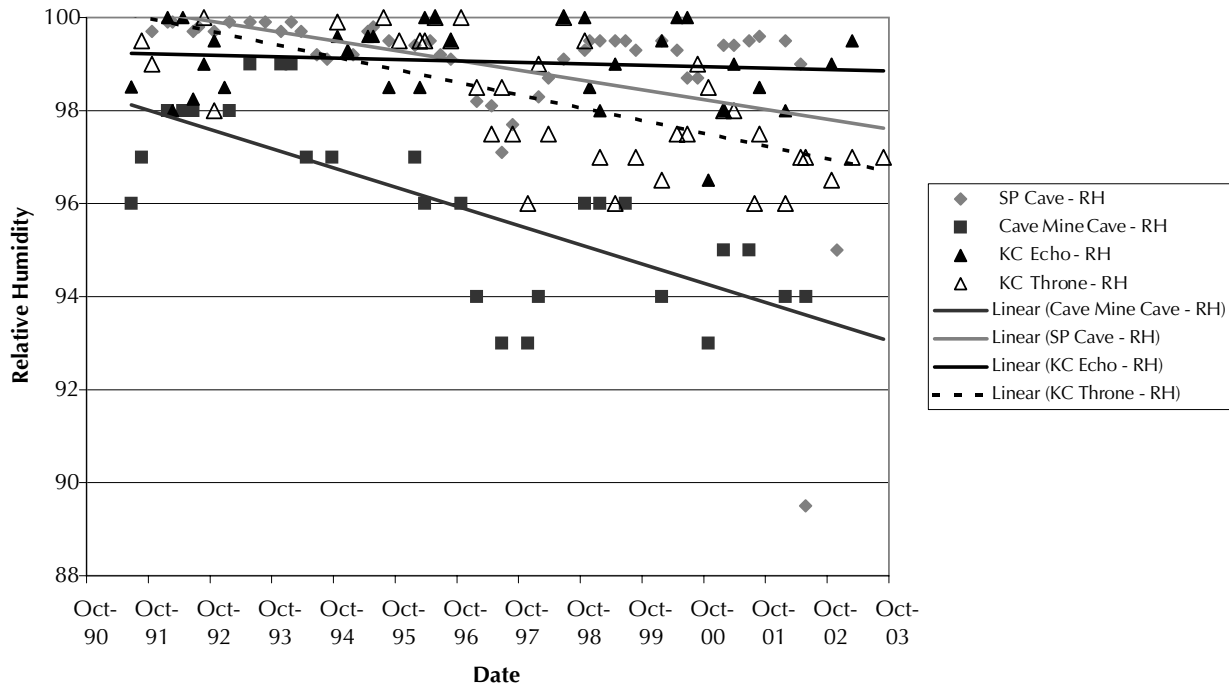


Figure 5—Humidity (and linear least squares best-fit lines for the humidity) of SP Cave, Cave Mine Cave, and the Echo Passage EMS and Lower Throne EMS at Kartchner Caverns.

Cave has decreased to even a greater degree than the humidity in the Lower Throne Room area of Kartchner Caverns.

Additional evidence of regional cave drying comes from Arkenstone Cave (Rincon Mountains, Pima County, AZ). Pool levels in the cave have been consistently falling over the past three years. The drying appears to be in response to regional drought (William Peachey, personal communication, 2003).

An additional useful dataset for evaluating humidity and temperature change in Kartchner Caverns is water levels in wells on and near the park. The wells measure the level of the ground water in several small, shallow aquifers in the area surrounding the cave. In particular, shallow, unpumped wells that sample water levels in the near-surface ground water systems around the cave provide useful information. These wells are not in the same perched aquifer as the cave; however, they still record the general area ground water responses to climate change. Because the cave water, including humidity, mud, and pooled water, is a portion of the local ground water system, regional changes reflected in the wells may also affect the cave. If the cave showed significant drying while the rest of the groundwater system did not, it would be reasonable to attribute the drying to causes other than regional climate response. However, as figure 6 shows, this is not the case. The water level in all wells has been generally falling since 1996. The water levels track the general drought conditions in the area fairly well as shown by the Palmer Drought Severity Index data in the graph. Like the changes at SP Cave and Cave Mine Cave, this evidence suggests that the drying in the cave is, to at least some extent, the result of regional climate conditions.

An additional dataset that provides some information on possible regional ties to climate changes observed at Kartchner is the surface climate data for the park. The surface temperature

of the area, as reflected by the mean daily temperatures recorded at the park's weather station between 1989 and 2003, has increased by about 3 °F (figure 7). Kartchner is not unique; National Weather Service data from Sierra Vista shows about 2 °F increase while that from Tombstone exhibits about 1 °F increase over the same period. The rise in the surface temperature in the area is potentially significant to understanding climate change in Kartchner Caverns. Although the temperature at Kartchner Caverns does not directly reflect the mean annual surface temperature (it is a few degrees higher than the surface mean annual temperature), it would be reasonable to expect that a rise in mean annual surface temperature to be reflected in a rise in the cave temperature.

Together, the data on Kartchner Caverns' climate change from the cave itself and from other regional data sources suggest that the climatic shifts seen at Kartchner Caverns are the result of both regional climate factors (probably a combination of both temperature increase and drought) and development-related activities (such as lights, tourists, and modification of airflow). Although the regional datasets indicate a strong regional signal for the cave, the pattern of variation within the cave shows that a development signal is also present.

Determining the extent to which the changes observed at Kartchner Caverns are caused by development-related causes rather than regional climate changes is more than an academic exercise. Many management decisions depend on understanding that balance. As Arizona State Parks tries to preserve the cave environment, many actions may help mitigate the changes. For example, misting in the cave with local well water may add moisture to the air to either compensate for increased temperature or moisture loss. However, mitigating natural changes could easily interfere with the natural function of the cave and would not be desirable. Understanding the balance

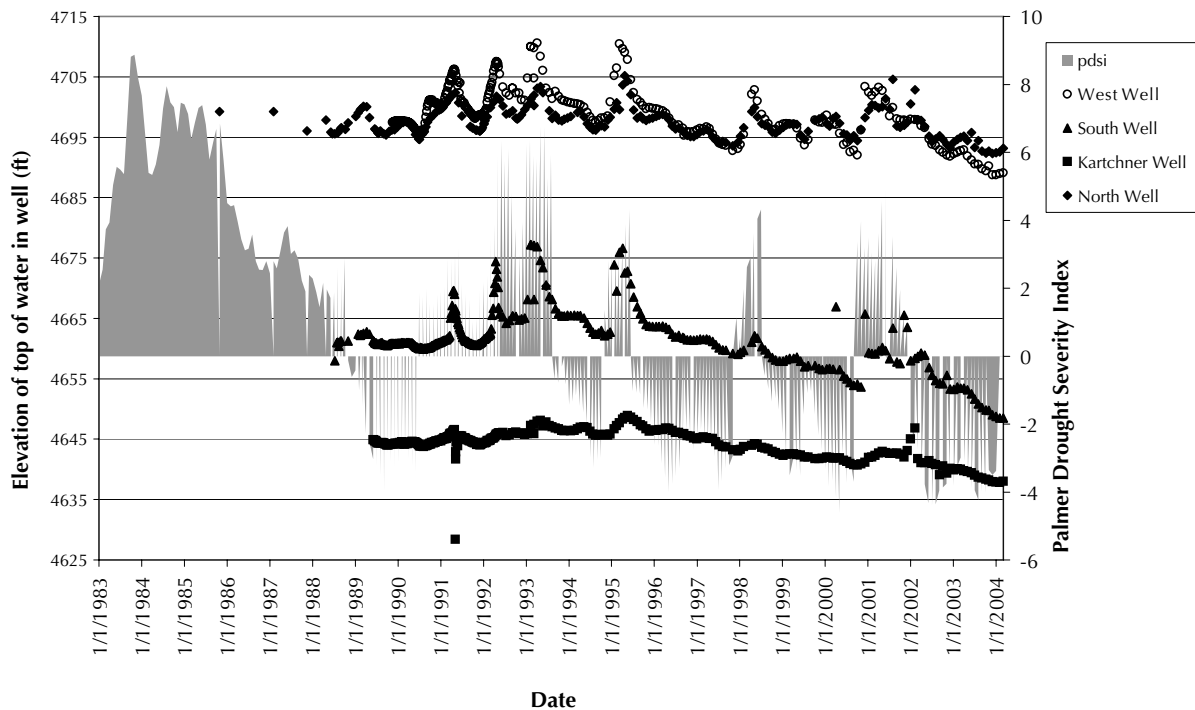


Figure 6—Water levels in unpumped wells around KCSP. These static levels represent the elevation of ground water in the well. Generally speaking, the higher the elevation in each well the more water within the aquifer. As levels fall, this represents less water stored in the aquifer. In addition, the graph shows the monthly Palmer Drought Severity Index (PDSI) for southeastern Arizona (NOAA-NSW AZ Region 7). The PDSI is an index of regional moisture conditions. Negative values indicate a moisture deficit; positive values indicate a surplus. Values below about -2 indicate significant drought conditions; values greater than about 3 indicate very moist conditions.

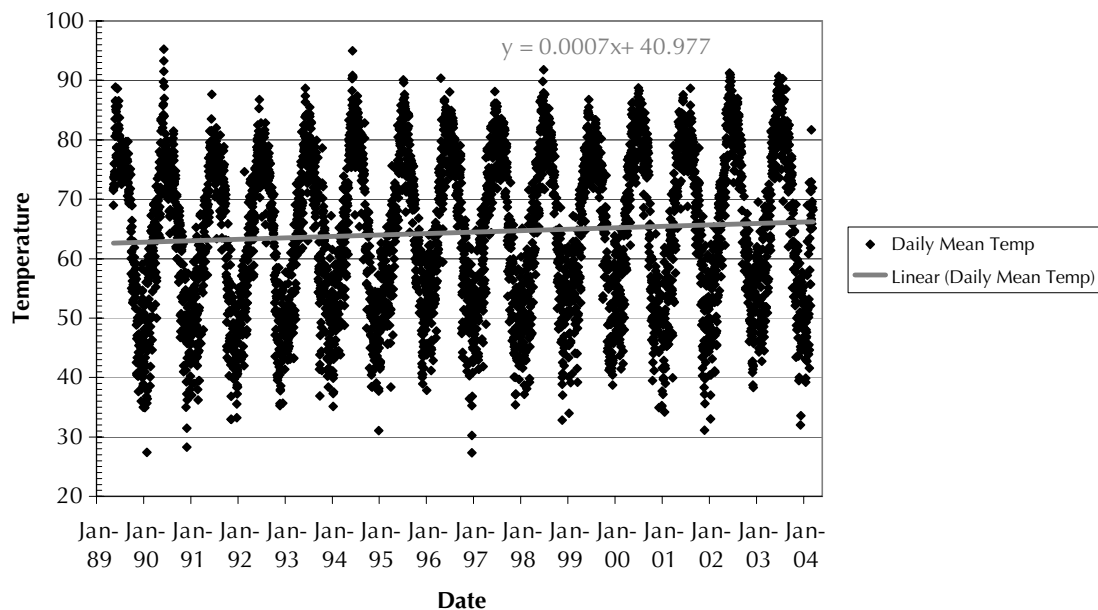


Figure 7—Mean daily temperatures (and linear least squares best-fit line) measured at Kartchner Caverns State Park weather station. The best-fit line demonstrates a trend toward rising surface temperatures at the park over the last 15 years.

of natural and anthropogenic changes will allow managers to make the correct decisions on how to address changes in cave environment.

Continued study and an expansion of regional monitoring networks will be necessary to better understand the roles of anthropogenic and natural regional changes in the warming and drying at Kartchner Caverns. An important by-product of this research will be developing datasets on cave climate that will help address related issues such as bat habitat requirements and regional patterns of climate change.

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