Kartchner Caverns State Park

2005 Environmental and Research Report

As I prepare to leave the agency for a new adventure, I am struck with great pride and sadness. I am proud because I believe that we have accomplished much for cave protection, management and study in the four years that I have been here. I am sad because there is so much left to do and so many on-going projects that I am going to miss being a part of.

Overall, my work over my time here has consisted of analyzing data derived from cave monitoring, improving monitoring systems, providing expertise on issues related to the operation and continuing development of Kartchner Caverns as an Arizona State Park, assisting our guides to better understand and interpret the cave, work with scientists from other agencies to promote further understanding of Kartchner Caverns, its processes and development.

My job as Science and Research Manager has involved working with numerous people from within State Parks and from outside agencies. I have loved every minute of it. The staff at Kartchner Caverns State Park has been a pleasure and inspiration. I can only hope that we may live up to the goals they set for us in their interpretation of the cave. I believe that the development of the Resources Management Section has been a fundamental shift for the agency. The shift is one that we will be proud of. Arizona State Parks Board and Executive staff have provided the support that is needed to protect the cave. I believe that they will continue to lead in the direction of proper stewardship.

Kartchner Caverns is fortunate to have a strong group of supporter throughout Arizona and beyond. They constantly challenge us to improve our study and protection of the cave. Among those supporters are the many scientists at many agencies that have assisted with the study of the cave. I have learned much from them during my tenure here.

I have been fortunate to have been so intimately involved with the study and protection of such a unique natural wonder as Kartchner Caverns. The passion that all who have been involved with the cave has been evident from the start.

I thank Arizona State Parks, the Arizona State Parks Board, and Ken Travous for the rich opportunity I have been afforded over the past four years. I look forward to assisting in the future as needed.

Rickard S. Toomey, III, Ph.D.
Science and Research Manager
Arizona State Parks
May 19, 2005

This report summarizes activities that we have undertaken and the results of some of those activities. It focuses on the monitoring and scientific studies that have occurred since the 2003 report. The report should not be viewed as a comprehensive analysis of the cave, scientific studies, or continuing work. It simply provides highlights of the on-going work. Discussions in this report are organized under the following general topics:

- Cave Environment and Climate
- Microbiological Studies
- Geological and Physics Studies of the Cave and Park
- Bats in the Cave and on the Park
- Geographic Information System and Databases
- Surface Land Issues Potentially Impacting Cave Resources
- Interagency Outreach and Cooperation
- New Scientific Publications and Presentations on KCSP.

Although I have been on staff for more than four years, some of the efforts outlined below are still in their infancy. The reasons for this include that many of the projects take time to develop, that we continue to begin new projects, and that results of work continue to drive us to ask new questions. Scientific conclusions based on the collected data are in many cases preliminary and are in some cases premature. Analysis continues as monitoring and management measures stabilize and take hold. For this reason Arizona State Parks must be vigilant in making sure that the data from Kartchner Caverns continue to be collected, that new approaches and techniques are applied to the cave, and that critical analysis of the data and conclusions continues.

Cave Environment and Climate

Activities and Observations:

- **Continued monitoring of the cave climate, carbon dioxide, and radon.**
- **Data from the cave indicate that cave temperatures continue to rise; and humidities have fallen (but appear to have stabilized somewhat).**
- **Cave and supplemental data indicate that regional climate patterns and development both contribute to the pattern of cave climate change**
- **University of Arizona Aeronautical and Mechanical Engineering design class have been developing an airflow monitoring system.**

Ranger Doug Graeme checking environmental stations (Toomey)

The first portion of this section contains a summary analysis of the data on cave climate and my observations about the significance of the data. More in-depth descriptions of the activities listed above follow that sub-section.

- **Continuing Analysis of Collected Data to Date**

The changing cave climate of Kartchner Caverns was discussed in some detail in Toomey (2002, 2003). This year's report continues the discussion of the changing climate. However, the data continue to support the general conclusions about the environmental change that are found in Toomey (2003). In short, those conclusions are as follows: 1) the cave has warmed and dried significantly compared to predevelopment conditions, 2) regional warming and drying are primary causes of the changes in the cave, 3) development has also contributed to the observed changes, and 4) insufficient evidence precludes sorting out the relative contributions of these two factors. Because the conclusions have not changed substantially, this report will discuss the current state of the cave; however, it will not repeat the in-depth discussion of additional lines of evidence presented in Toomey (2003), Toomey and Nolan (in press), and Cigna and others (in press).

The data collected from the cave since 1988 indicate that changes in the cave microclimate have occurred and are continuing to occur. While some of these changes appear to be tied to the development of the cave, others appear to reflect regional warming and on-going drought conditions. The analysis of the additional year of data from Kartchner, as well as, additional data from other caves and from non-cave sources strongly supports this conclusion. Sorting out the various contributing causes to these changes remains elusive. Some of the factors are probably anthropogenic (human-caused); others are the result of natural processes. Still others may result from the interaction between development and natural changes. This report presents a summary of some of the data collected since the 2003 report.

In order to facilitate comparison with previous reports, I have maintained some of the conventions from that report. I will first present individual discussions of several areas of the cave, using the same areas used last year.

Discussions of cave climate focus generally on measures of cave temperature and moisture. The temperature measure used here is air temperature, while the measure of moisture is relative humidity. **Figures 1, 2,** and **3** summarize the temperature and moisture histories at the three stations. Each graph shows the air temperature at an environmental station (small beige diamonds), a five-reading moving average of the air temperature (red line), the relative humidity at the station (small blue squares), and a five-reading moving average of the relative humidity (blue line). Because the individual data vary from reading to reading, the moving averages provide the most straightforward tracking of temperature and humidity.

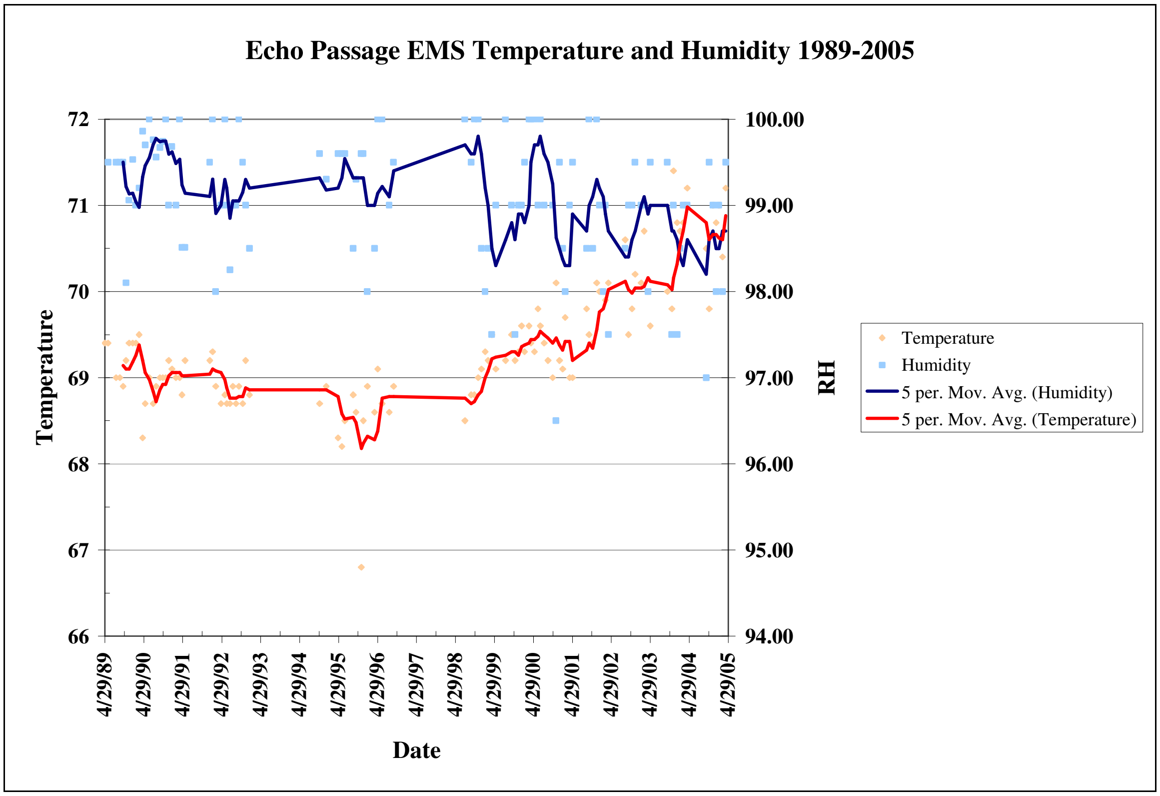


Figure 1 -- *Temperature and relative humidity data and trend at the Echo Passage environmental monitoring station (EMS-10).*

Echo Passage

Figure 1 shows the climate data from the environmental monitoring station in Echo Passage. This station is the existing deep-cave station that is farthest from current development impacts or visitor tours. The data suggest a small change in temperature or humidity has occurred in this area. The temperature during the development and tour phase (October 1998 to present) shows a notable increase (about 2º Fahrenheit compared to pre-development temperatures). This value represents a continued increase from the temperature of this area in the 2003 report. The apparent leveling of the temperature trend that was noted in Toomey (2003) ended and another period of more rapid increase occurred in 2004. There has subsequently been another apparent leveling of the temperature, but now at a temperature a bit below 71ºF. The humidity shows a small but statistically significant decrease during the period of development (from a mean relative humidity of 99.3% from 1989-1998 to a mean of 98.81% from 1999 to the present; unpaired, one-tailed, heteroscedastic, t-test probability $p = 7.7 \times 10^{-5}$), and it shows somewhat greater variability in humidity from reading to reading (1989-1998 standard deviation 0.57 to 1999-Apr 2005 standard deviation 0.83). The mean humidity has decreased slightly since 2003. Overall, this station continues to show the least change of any regularly monitored station. However, it does appear to be showing some influence from the opening of the Big Room and regional climate change.

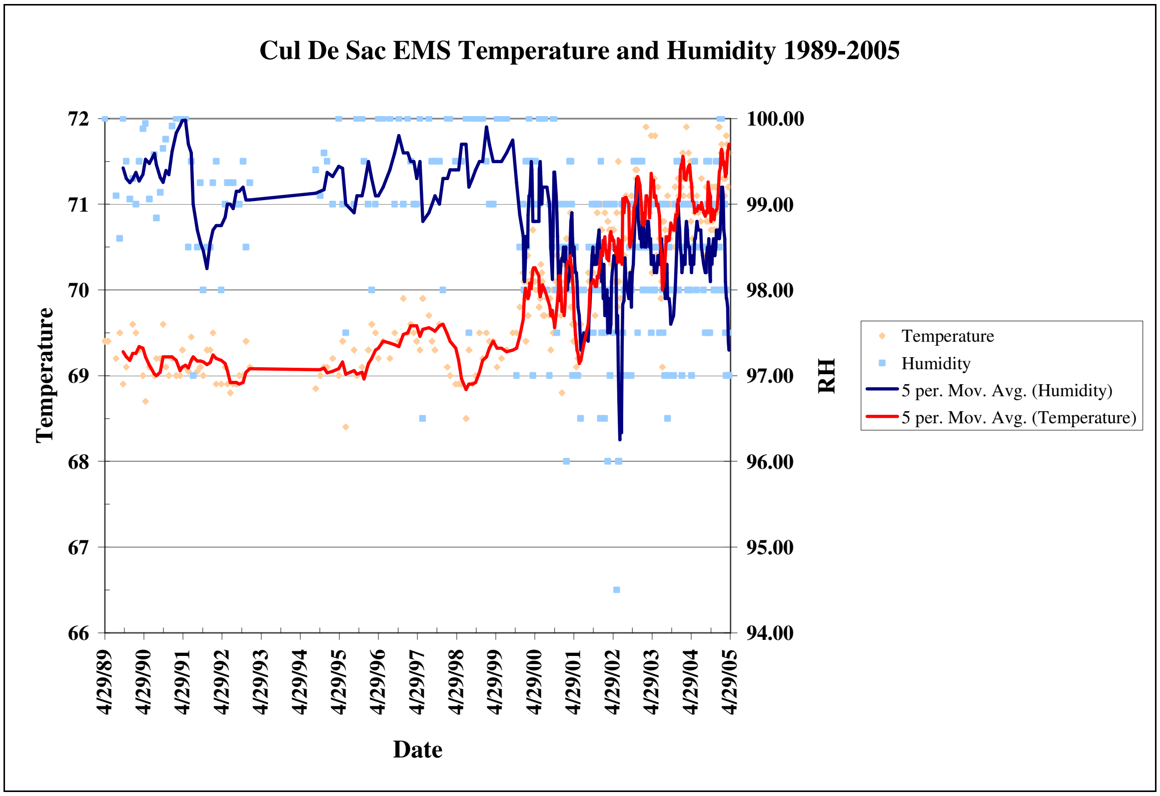


Figure 2 -- *Temperature and relative humidity data and trend at the Cul De Sac environmental monitoring station (EMS-7).*

Cul De Sac

The Cul De Sac environmental monitoring station shows a somewhat larger change in temperature and humidity (**Figure 2**) than seen at Echo Passage. This station is near the Big Room tour trail. The data from Cul De Sac shows an approximate 2º Fahrenheit rise in temperature since the beginning of 1999. Toomey (2003) noted a reversal of the warming in that year. That reversal ended and now temperatures are about 0.5º Fahrenheit higher than in 2002; however, there was an additional reversal during 2004.

An important difference between the Cul De Sac and Echo Passage trends is that the temperature change in the Cul De Sac is accompanied by a larger change in humidity as well. Between 1989 and the end of 1998, the humidity at the station had a mean of 99.28% (standard deviation 0.73%). Since the beginning of 1999 the humidity at the station has been generally lower and more variable (mean 98.40%; standard deviation 0.90%). The decrease in relative humidity at this station between these periods is statistically significant (unpaired, one-tailed, heteroscedastic, t-test probability $p = 8.2x10^{-16}$). The humidity trend has been relatively stable since the 2003 report; the mean humidities from 1999-2003 and 1999-2005 are the same. The standard deviation from 1999-2005 is actually lower than it was for 1999-2003; this suggests that the variability of the humidity may be decreasing.

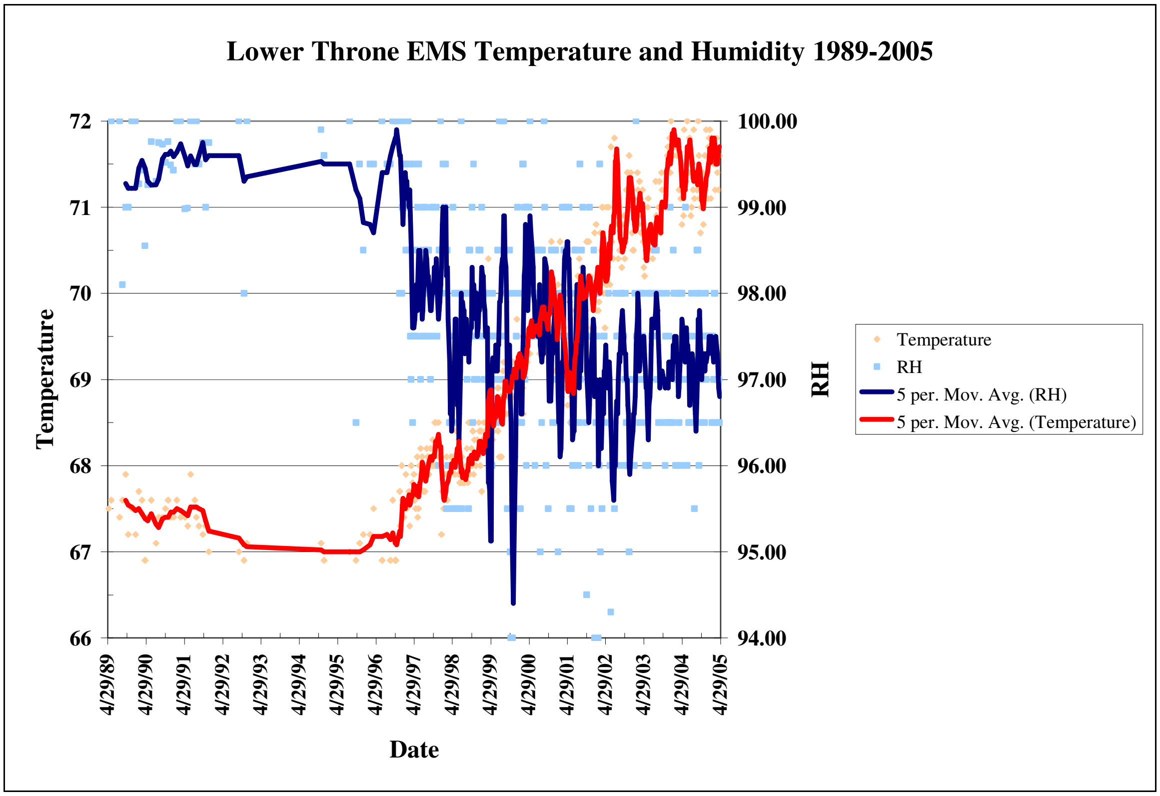


Figure 3 -- *Temperature and relative humidity data and trend at the Lower Throne environmental monitoring station (EMS-17).*

Lower Throne

The Lower Throne environmental monitoring station exhibits notably larger changes in temperature and humidity than are found at the stations discussed earlier (**Figure 3**). This station is in the Rotunda-Throne Room section of the cave. This station has been subject to changes associated with development (development lighting and personnel levels, construction, concrete pours) and those impacts associated with tours (lighting and visitation levels). The graph of the data from Lower Throne shows an approximately 4º Fahrenheit rise in temperature between the beginning of 1997 and the present. The temperature at this station shows some indication that it may be stabilizing at about 71.5º Fahrenheit. Whether this will be a long- or short-term stabilization is not clear. 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%). Between the beginning of 1997 and the present, the humidity at the station was generally lower and more variable (mean 97.42%, standard deviation 1.26%). The means and standard deviations from 1999-2003 and 1999-2005 are virtually identical. This suggests the possibility that humidity, like temperature, might be stabilizing at this station. The station in the Rotunda continues to show a similar record of environmental change to that shown for Lower Throne station. The temperature rise at the Rotunda station since the beginning of 1997 is approximately 4.5º Fahrenheit; this rise is slightly larger than that at the Lower Throne station. As at Lower Throne, there is some indication that temperature may be stabilizing. The humidity change is less pronounced in the Rotunda than in the Throne Room (1989-1996 humidity mean 99.26%, standard deviation 0.87, 1997-2005 humidity mean 98.40%, standard deviation 1.19). The humidity difference in the Rotunda between these two periods, although smaller, is still highly significant statistically (unpaired, one-tailed, heteroscedastic, t-test probability $p=8.1x10^{-9}$).

The moisture change in the Rotunda and Throne does present another interesting paradox. Although the amount of moisture in the air in those rooms has decreased as measured by relative humidity, the absolute humidity (a measure of the actual mass of water vapor in the air) has increased. In predevelopment studies the absolute humidity at the Lower Throne station was approximately 17 grams per cubic meter. Now the absolute humidity is nearer 18.5 grams per cubic meter. The reason for this is that the air's increased temperature allows it to hold more moisture than it previously could. So, although the air "feels" drier, there is actually more water in the air.

The spatial variation in temperature change in the cave has led to a major change in the overall temperature pattern of the cave. During predevelopment, the Rotunda and Throne Rooms were significantly cooler than the Big Room. However, because the Rotunda and Throne Rooms have warmed more markedly than the Big Room, they are now nearly the same temperature or slightly warmer. Ultimately, this change may have profound effects on the overall airflow in the cave. It is not clear whether the Big Room temperature will rise to re-establish the previous pattern or whether the new pattern is permanent.

Significances of Cave Climate Change

Unfortunately, it is not possible at this time to determine what proportion of the temperature and humidity change seen in the cave is related to regional signal, what proportion is related to development, and what proportion is related to an interaction of these factors. Cigna and others (in press) concluded that data from outside the cave suggest that regional climate change may be the dominant cause of the climate changes seen at Kartchner Caverns. If we were able to adequately separate these factors, we would be in a much better position to understand the observed climate change and to determine what actions ASP should take to deal with them. Unfortunately, development of the cave largely coincides with an apparent change in Arizona’s climate to a drier mode. That has complicated the effort to separate the causes.

In Toomey (2003) I noted the following (p. 16):

> Ironically, recognizing that the change seen at Kartchner Caverns may be (at least partially if not largely) the result of regional climatic changes makes our job of conservation and protection much more difficult for several reasons. First, although it may be palatable to say that the changes we see are not our fault, this also means that we lack significant ways to reverse the changes. If we were able to identify the changes we see as caused by problems in development, we could try to take actions that would fix those development issues. We are not able to do the same with large-scale climatic patterns. Second, the regional changes could actually serve to mask changes that are caused by development.

> We cannot become complacent by saying that the changes are natural and beyond our control. To do so, we risk missing opportunities to fix problems that are the result of management actions. The mix of natural and development related changes also leaves us with an important dilemma from a conservation standpoint. How far do we go to mitigate changes that are a mix of regional and local developmental changes? Would it be both counter-productive and potentially damaging to the cave to mitigate natural changes artificially? Such a dilemma is not likely to be resolved soon, particularly since the on-going drought and warming are both conditions that may continue for an extended time.

Unfortunately, as I prepare to leave the agency, the quote above continues to express both the state of our knowledge concerning the climate changes and the dilemmas that we face as we try to address them. I urge Arizona State Parks to remain vigilant in analysis of the changes and to expand efforts to find additional data that might help sort out the various causes.

One such effort is to get better measurements on airflow to examine what changes have taken place in overall airflow due to development, tours, and regional climate change.

- **<u>Developing an Airflow Measuring System</u>**

Since the beginning of 2004 we have been working with a senior Aeronautical and Mechanical Engineering class at the University of Arizona to develop a datalogging airflow measurement system that can be used in the cave (initial placements will include the Blowhole and the entrance to the River Passage). A group of five students (Dustin Brandt, Robert Davidson, Erin Fidler, Nicholas Foster, and John Key) under the direction of Dr. Reid Bailey worked on the system as part of a two semester sequence of classes in which they attempt to solve a real-life engineering problem. After studying the problem, they chose an ultrasonic anemometer based system and developed some data capture hardware and software. They tested their system and got limited data. Several members of the group are continuing to refine the hardware and software for use in the cave. We hope to install the system and begin getting data during 2005. They also produced a comprehensive report analyzing the problem and possible approaches to it. I am especially pleased with our participation in this project. It provided an opportunity for us to work with enthusiastic students to fulfill both ASP's educational mission and resource management needs.

- **<u>Radon licensing</u>**

In 2002, the Arizona Radiation Regulatory Agency (ARRA) issued a radon license to ASP for development and operations. The University of Arizona Radiation Control Office has worked with ASP to develop a radon monitoring program and has agreed to oversee ASP’s radon monitoring activities. Under the radon program, radon decay products are measured daily in two areas of the cave (both tour sections). This data is combined with amount of time each employee or volunteer spends in the cave to quantify each person's radon exposure. That exposure is tracked by the Cave Unit, under the direction of Radon Safety Officer, Ginger Nolan, to ensure that no one exceeds recommended exposure levels.

The Occupational Safety and Health Administration Permissible Exposure Limit for radon is 4.0 working level months per year. Exposure is calculated using the average amount of radon decay products a person may be exposed to (such as the data shown in the graph below) along with the duration of the exposure to decay products. In 2004, the highest exposure level operations worker was less than 2 working level months.

Figure 4 shows the measured level radon decay products at various places in the cave. Although there is broad overlap of readings from different seasons and places, a few generalizations are possible. In general, radon levels in any one area are higher in the summer and lower in the winter. Readings during development average slightly higher than those that have been measured during tour operations. Several factors may account for these observed differences. Slightly different techniques were used for measuring radon levels during development compared to operations. This difference in measurement technique may also contribute to the apparent change in radon levels. Rock breaking and disturbance of fill may allow more radon to reach the air; this type of activity was common in development and is rare during operations. A third possible factor is the temperature change that has been observed in the cave. The changing temperature may affect airflow into and out of the cave. The amount of outside air that mixes with the cave air is an important factor for determining radon levels. The levels that have been observed over the last seven years are similar to those observed in pre-development studies.

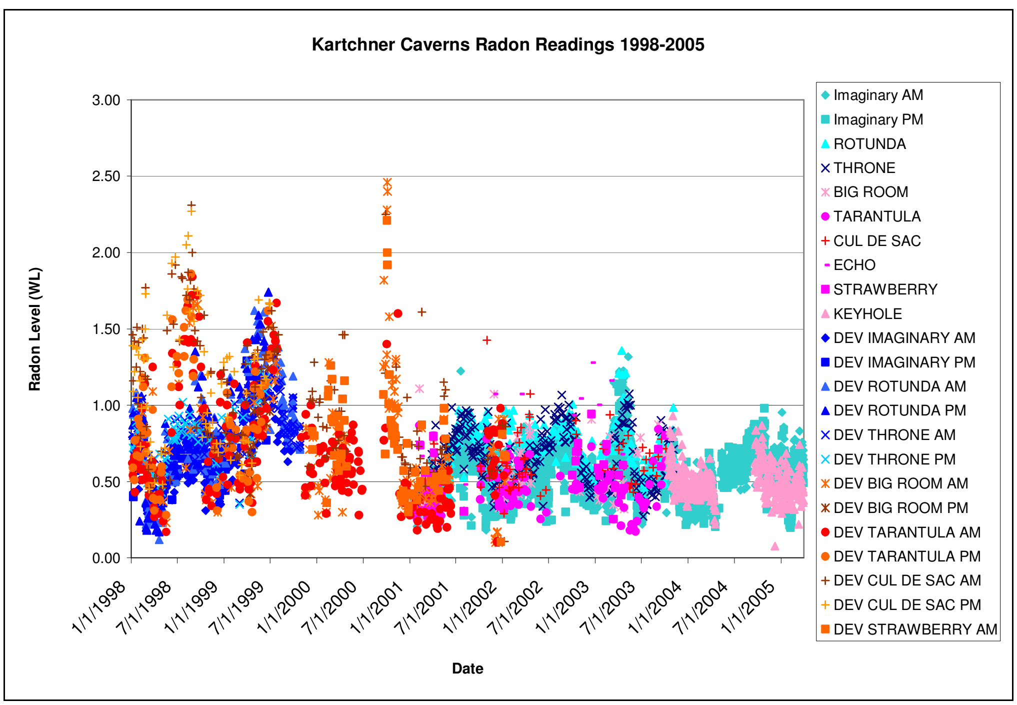


Figure 4 – *Radon decay products levels, expressed in working levels, in various parts of Kartchner Caverns. Readings shown in shades of red, pink and orange are from the Big Room complex. Readings in shades of blue are from the Rotunda and Throne Rooms. Development readings and operations readings are shown in different symbols (as noted in the legend).*

- **Monitoring Carbon Dioxide Levels**

Elevated carbon dioxide levels can affect the cave health by increasing dissolution of calcite, by slowing deposition of speleothems, and by encouraging growth of algae. Monitoring of carbon dioxide was accomplished using a Draeger pump system for spot measurements in developed and undeveloped areas until late 2004. At that time we acquired a Telaire 7001 carbon dioxide meter; this meter has allowed us to greatly expand monitoring of carbon dioxide levels. Current data indicates that carbon dioxide levels in Kartchner vary greatly in space and time and that they remain comparable to those obtained in the pre-development. With the increased data, we hope to be able to get a better idea of how carbon dioxide varies in space and time in the cave.

Figures 5 and **6** show several aspects of the variation of carbon dioxide in space and time. **Figure 5** shows data for a single location throughout the year. **Figure 6** shows the complete record of carbon dioxide for the cave and shows both the temporal and spatial variation.

Carbon dioxide in Kartchner Caverns varies seasonally and geographically within the cave. Atmospheric carbon dioxide levels outside average about 330 parts per million (ppm). CO_2 levels are higher inside the cave than outside for several reasons. We know that the water dripping into the cave out-gases CO_2 as it deposits calcite cave formations. Carbon dioxide then builds up in the cave. Since CO_2 is picked up in the soil and comes in with water, you might expect levels to be higher when either more CO_2 occurs in the soil (growing season) or when more water comes through the soil (winter or monsoons). The carbon dioxide level in the cave will also be reduced when fresh air from outside comes into the cave. In the winter we have increased ventilation of the cave (due to density driven air circulation, i.e. chimney effect), this leads to lower measured CO_2 (**Figure 5**). We also find lower levels in areas where circulation of fresh air is better, that is in the Big Room which is nearer the entrance (**Figure 6**).

Development and tourism in the cave may cause a rise in the level of CO_2 in the cave, as a result of the exhalation of CO_2 from people working in or touring the cave. This exhaled CO_2 might theoretically cause an eventual long-term rise in CO_2 in the cave. However, data from predevelopment studies and present monitoring shows only a small increase in CO_2 levels in the Throne Room. Limited pre-development measurements showed the area to have a mean CO_2 level of 3125 parts per million (ppm) (range 1660-5400; standard deviation 1196 ppm); measurements during development and tours provide a mean of 3177 ppm (range 1000 – 6100 ppm; standard deviation 1205 ppm). The observed rise is not statistically significant (unpaired, one-tailed, heteroscedastic, t-test probability $p=0.44$) and is much smaller than the potential rise predicted in ACPI studies. If data from during development are ignored (comparing only pre-development with tours), the rise is slightly more pronounced (tour mean 3268 ppm; range 1250-6100 ppm; standard deviation 1151 ppm). However, this rise is also not statistically significant (unpaired, one-tailed, heteroscedastic, t-test probability $p=0.34$). Although the data from other areas of the cave are much sparser, they too suggest no demonstrable rise in the CO_2 levels due to development and tours. Even the highest levels of CO_2 found in the cave are not considered harmful for people, based on guidelines from the National

Institute of Occupational Safety and Health (10,000 ppm for 8-hour exposure and 30,000 ppm for 15-minute exposure).

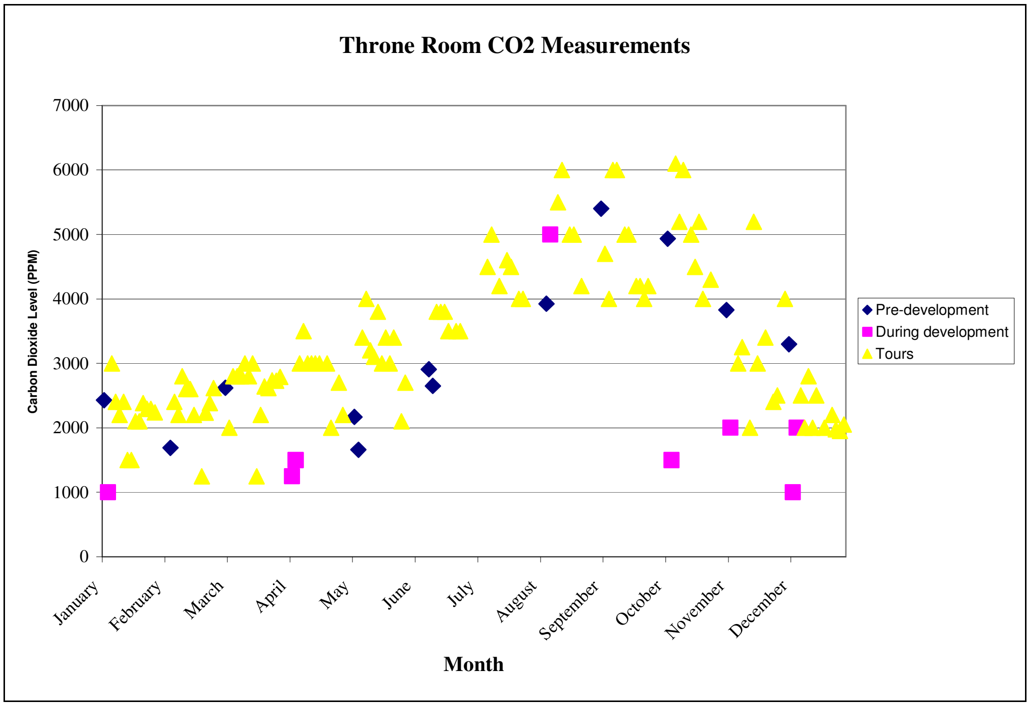


Figure 5 – *Measured carbon dioxide levels in the Throne Room by month. The graph shows data from 1990 through March 2005.*

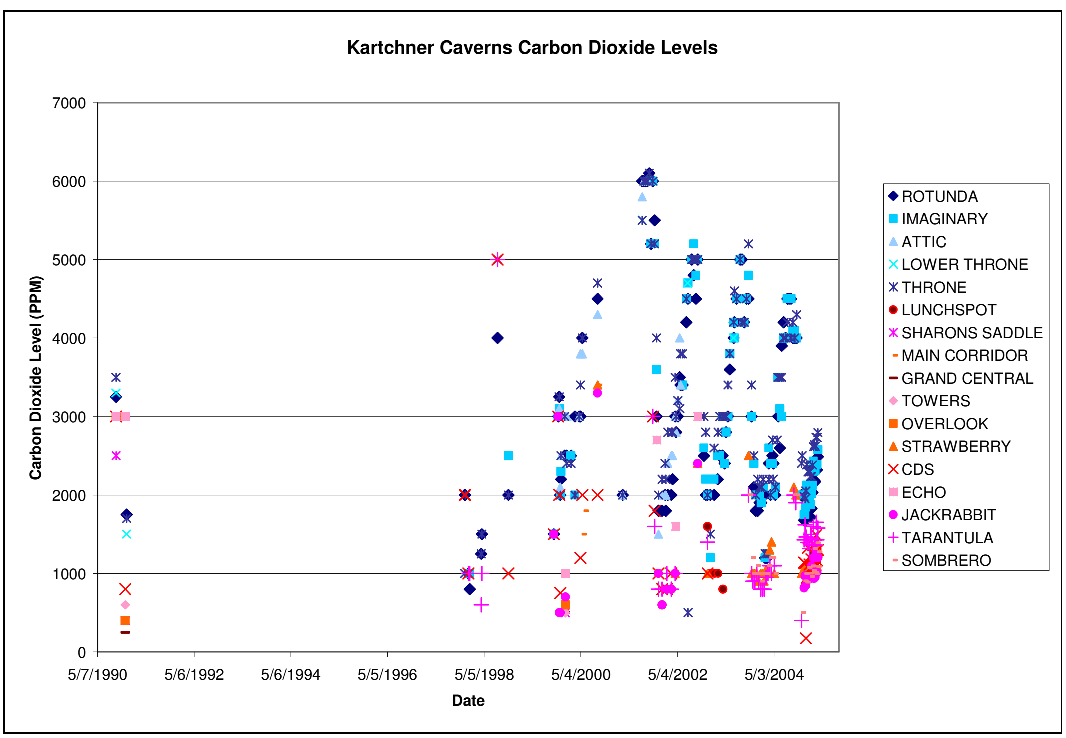


Figure 6 – *Measured carbon dioxide levels in Kartchner Caverns from 1990 through March 2005. Data points in shades of blue represent readings from the Rotunda and Throne*

Rooms. Data point shown in shades of red, pink, and orange represent data from the Big Room complex. It is important to note that we have little data on summer levels for the Big Room due to closure for bats.

Microbiological Studies

Activities and Observations:

- **Luisa Ikner completes Master's thesis on microbiology of Kartchner Caverns.**
- **Monitoring of Big Room for microbial changes associated with tours.**

Microbiologist Julie Neilson taking swab sample from bedrock surface(Toomey)

Toomey (2002, 2003) discussed a variety of biological issues at the cave; one of these, the development of bacterial "slime" on painted fiberglass surfaces in the Rotunda and Throne Rooms, has developed into one of the most interesting and important pieces of research that the cave has supported. Luisa Ikner completed her master's thesis on the microbial diversity in selected areas of Kartchner caverns and human impacts on that diversity (Ikner, 2004). Luisa worked under Dr. Raina Maier of the Department of Soil, Water and Environmental Sciences at the University of Arizona.

Ikner (2004) found that heterotrophic bacterial diversity varied greatly between the high human impact areas (on and along the tourist trail) and lower human impact areas (in Grand Central Station and in the Subway). She was able to isolate and culture nine unique heterotrophic bacteria from the painted fiberglass, 21 from rock surfaces in high impact areas, 26 from rock surfaces in moderate impact areas, and 32 unique heterotrophic bacteria from rock surfaces in low impact areas. In addition to changes in the numbers of taxa, the types of bacteria also vary greatly in different impact regimes. Ms Ikner concludes that the differences in bacterial diversity may result primarily from indirect impacts of people (such as increasing organic material due to sloughing of skin cells and lint as well as changing the temperature and humidity in the cave).

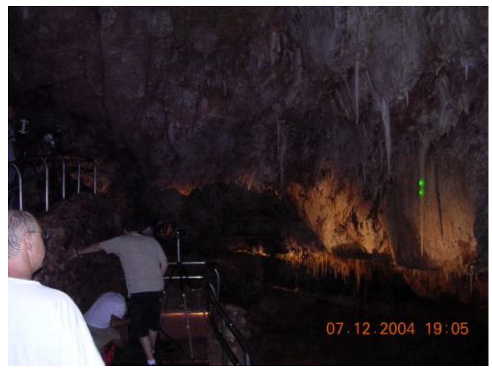
Information on bacterial slime development on painted fiberglass surfaces has already been used to modify cave management. In the Big Room, different techniques were used to hide infrastructure. In some cases stucco coverings were used instead of fiberglass. In others plastic structures were used to hide infrastructure, but these plastic structures have coloration encapsulated in the plastic where it is less available to bacteria. So far we have not seen development of bacterial slime in the Big Room to the degree that it was found in the Rotunda and Throne.

Dr. Maier has also begun a microbial monitoring program for the Big Room. This program uses swab sampling of areas near the trail and far from the trail to track changes in microbial diversity as tourism proceeds. The first samples were taken before tours began in the Big Room. They provide a post-development, but pre-tours baseline for the study. I urge Arizona State Parks to continue funding of this monitoring effort. It will provide valuable information about the microbiological effects of tourist activities in caves.

Geological and Physics Studies of the Cave and Park

Activities and Observations:

- **University of Arizona physicists publish work on speleothems formation processes**
- **Arizona Geological Survey publishes geological map of McGrew Spring and Benson Quadrangles.**
- **University of Arizona geologists extending work on structural geology of Kartchner Block and regional climate change.**



Physicists photographing stalactites to study their shape (Toomey)

Several important geological and physics projects have taken place over the past year. Perhaps the most exciting from a scientific standpoint is the work led by University of Arizona physicist Ray Goldstein and his graduate student Martin B. Short. Their research team has been using fundamental physical and geological principles to develop rigorous mathematical models of how speleothems grow. This work has already led to the publication of a ground-breaking paper that derives a growth law and underlying ideal shape for carrot-type stalactites (Short *et al*., 2005). After Dr. Goldstein and his team developed the mathematical model for stalactite shape, they used stalactites at Kartchner Caverns to test the results of their model. They found very good agreement between the real stalactites and the model. They are continuing work to both expand the original study and to begin study of additional speleothems types and features. I anticipate several more papers from this group in the future.

The most important geological study from a cave protection standpoint is probably the completion of the area geological mapping by the Arizona Geological Survey (AGS). AGS geologists Todd Shipmann and Charles Ferguson completed mapping the McGrew Spring and Benson USGS 7.5-minute quadrangles. The McGrew Spring map was published in late 2003 as part of the Survey's Digital Map Series (DGM-35; Shipmann and Ferguson, 2003). These maps provide an important tool in better understanding the geology of the park and how it fits into a regional framework.

We have continued our close relationship with the UA Department of Geological and Mining Engineering. Dr. Bob Casavant and his students continue their research into the structural geology of the Kartchner Block. This work has resulted in a better understanding of how the block fits into the regional tectonic framework. It has also resulted in a new model explaining how the block was emplaced. This new model helps explain not only many features of the block, but it also explains many features of cave formation.

We are also continuing to work with Dr. Julia Cole and several other researchers from the University of Arizona, Department of Geosciences, to use Kartchner Caverns to study regional climates of the past 100,000 years. This work could potentially allow us to better understand the long-term history of the cave environment. They are preparing a proposal to study the age and geochemistry of stalagmites in Kartchner. I recommend allowing them to use stalagmites that have been moved in construction, if any are suitable. These studies may benefit the cave by providing information on the past climate of the cave that can be a valuable supplement to our predevelopment measurements.

Hydrological Studies of the Cave and Park

Activities and Observations:

- **Water levels in shallow wells continues to fall due to continued drought**
- **United State Geological Survey hydrologist installs sensors in cave to detect infiltration.**
- **Cooperative Extension and University of Arizona's SAHRA complete DVD interpreting hydrology of block and cave.**
- **Participated in Arizona Hydrological Society annual meeting 2004.**

Toomey and Blasch install water flow detectors on the surface of cave formations (Nolan)

We continue to study the hydrology of the park and cave; however, the on-going drought has limited much of the work. Since 2001, hydrological measurements in Guindani Wash on the park have confirmed that no sustained surface flows have occurred in the wash. These results are not surprising given the lack of rain, falling local water tables, and soil moisture deficits.

We have continued to monitor water levels in shallow, unpumped wells around the park. These wells measure the level of the groundwater in the area surrounding the cave. The data that is most useful comes from the Kartchner, North, South and West Wells (as defined in the pre-development studies). They record natural changes in the water level that are driven by climate changes rather than changes in area water use. None of the wells is in exactly the same perched aquifer as the cave (they are in surrounding alluvial aquifers); however, they still record the general area ground water responses to climate change. The water level in all wells has been falling steadily since at least 1996 (**Figure 7**). 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. As of May 2005, the wells are at or very near their known historic lows in terms of water levels. Measured water levels have fallen between 10 and 15 feet since the predevelopment measurements with almost all of the decrease happening after 1996.

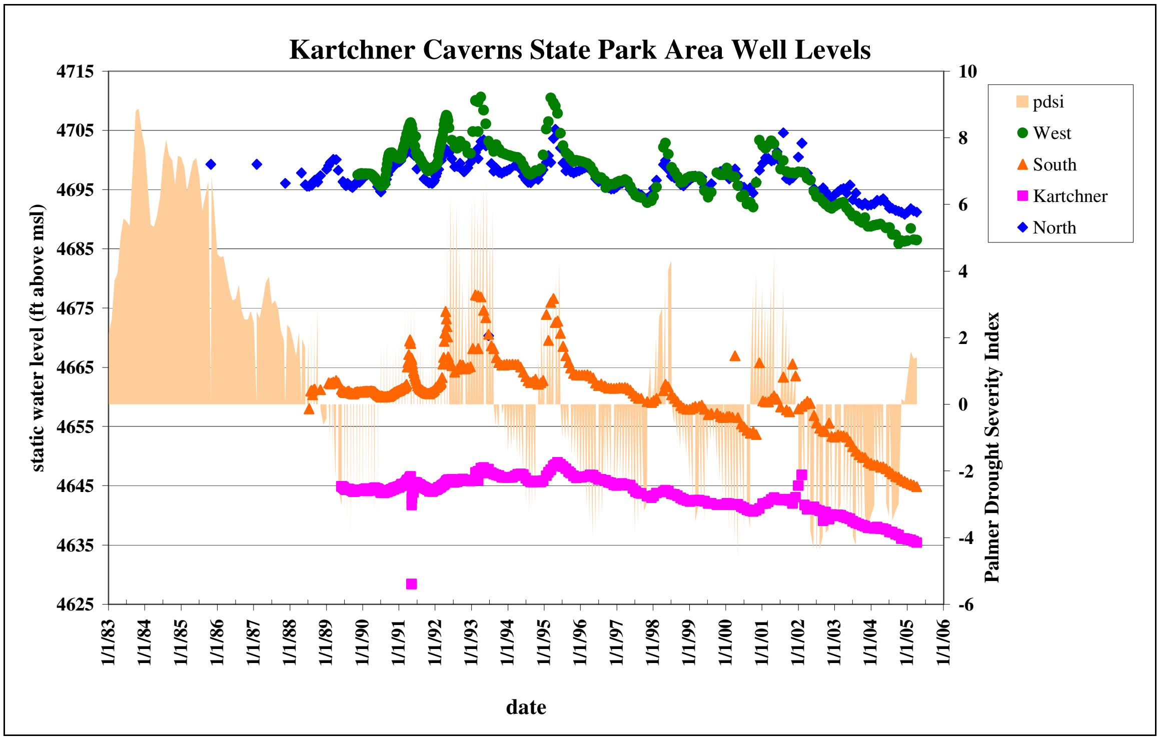


Figure 7 – *Water levels in unpumped wells around KCSP. These static levels represent the elevation of the water below ground. The higher the elevation of the water, the more water in the aquifer. As levels fall, this represents less water stored in the aquifer. In addition, the graph shows the monthly Palmer Drought Severity Index (PDSI) for the 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.*

We have been working with Dr. Kyle Blasch (United State Geological Survey) to better understand the timing of both stream flow and direct cave water percolation in the cave. He has installed a variety of sensors in the cave (and in some surface washes) to detect when water begins flowing. Some of these are in cave stream channels, some are in areas of pooling, and others are on the surfaces of speleothems. We hope to use these sensors to precisely determine when water begins flowing in parts of the cave. We further hope to be able to tie these results to rainfall information to better understand infiltration of water into the cave. Unfortunately, the extended drought conditions have meant that we have not yet detected infiltration events in the cave.

The Cochise County Cooperative Extension, the Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) center of the University of Arizona, and the Department of Hydrology and Water Resource have developed a computer exhibit focused on the hydrology of the Whetstone Mountains and Kartchner Caverns. This exhibit is available at a computer kiosk at the Discovery Center, online, and as a DVD being sold at the park's gift shop. The development of the exhibit was funded through a grant to the Cooperative Extension.

Kartchner Caverns State Park was well represented at the 2004 Arizona Hydrological Society annual meeting. Chuck Graf (Arizona Department of Environmental Quality) presented a paper on the exploration and predevelopment studies at the cave. I followed with a discussion of our on-going monitoring and environmental change at the cave. Bob Casavant (University of Arizona) presented his tectonic model of the Kartchner Block and discussed implications for hydrogeology. The park also hosted an all-day field trip from the meeting. Participants were treated to a tour and discussion of the geological and hydrological features of the park and cave.

Bats in the Cave and Park

Activities and Observations:

- **Bats continue to use cave despite opening of Big Room.**
- **Continued monitoring and archiving of bat sightings on Park.**
- **Implemented bat-based Big Room closure protocols**
- **Dr. Ronnie Sidner and Ms Debbie Buecher conduct study to develop bat call library using Kartchner Caverns**
- **Dr. Karen Krebbs completes study lesser long-nosed bat use of agave on park.**
- **Big Room guano dated**

Ranger Kathy Smith counting bats in sinkhole (Toomey)

The bats at Kartchner Caverns are vital to the cave's continued environmental health because they provide the guano that is the basis for the cave's internal ecosystem. The cave serves as an important maternity roost for the southwestern cave *Myotis* (*Myotis velifer*). Our monitoring of the bat usage of the cave indicates that they continue to use the cave in numbers comparable to those seen prior to development.

Figure 8 shows the bat exit counts for each of the last 18 years (through May 17, 2005). The graph shows the counts that were made of bats exiting the cave from about one-half hour before sunset until it becomes too dark to see bats leaving. Although every bat may not exit the cave during this time, the counts provide a good indication of the number of bats using the cave. The graph indicates that bat usage at the cave continues to be strong, although there is significant variation from year to year. This variation probably results from a number of factors including weather, food supplies, available regional populations, and other available regional roosts. Each of these factors probably varies on a yearly basis, and thus the population at Kartchner does as well. In addition, local factors may lead to variation in both bat usage and bat counts. Local factors that might effect bat usage include changes in cave environment due to development and predator activity (which has occurred on several occasions over the period of monitoring). Local factors that have an effect on bat counts (but not necessarily actual bat numbers) include staffing levels and how local monsoon storm timing matches with scheduled bat counts.

Overall, the bat population continues to appear healthy. The somewhat below average peak count in 2004 may be the result of predation by a family of ringtails (*Bassariscus astutus*) causing partial roost abandonment during the late summer that year. However, I recommend continued vigilance in counting bats and looking at anomalies in their numbers. If peak counts continue to fall below long-term averages, we may need to further examine what other factors may be affecting bat usage of the cave.

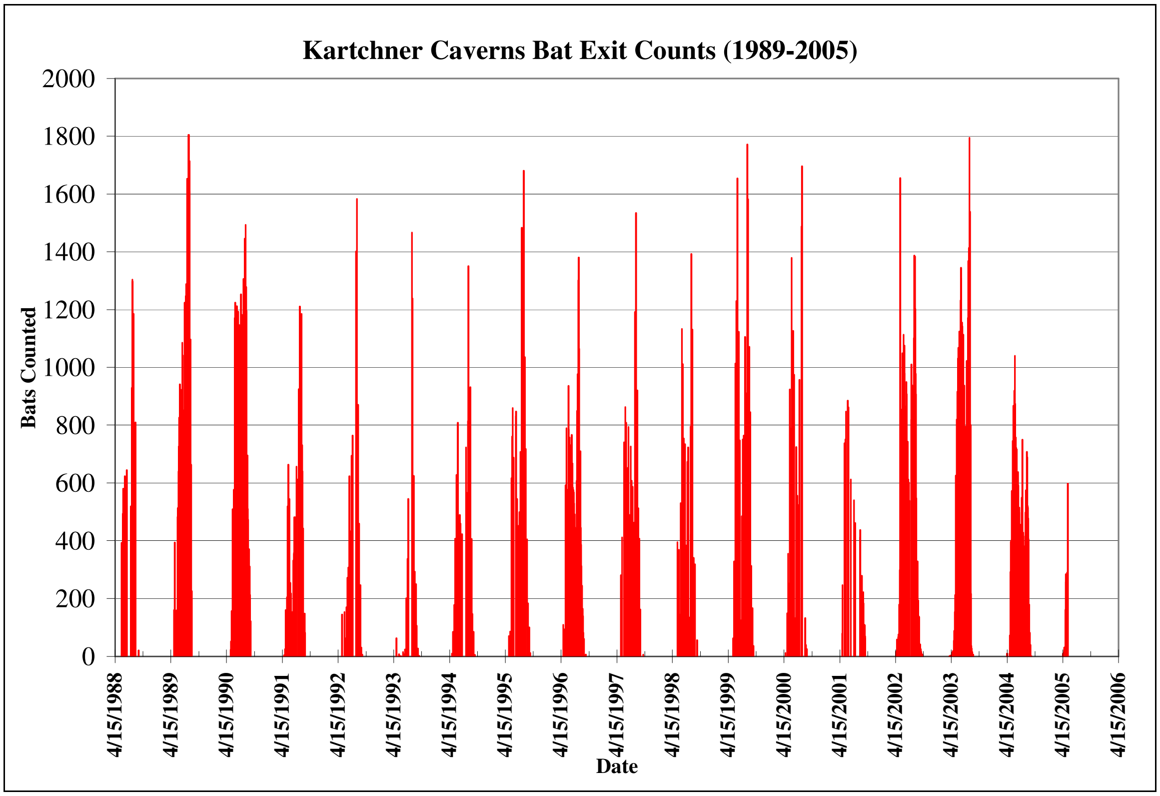


Figure 8 – *Kartchner Caverns bat counts from 1988 to the present.*

In addition to the maternity colony of cave *Myotis*, several other bat species occupy the Park, including a small maternity colony of Mexican long-tongued bats, a moderate-sized colony of Mexican free-tailed bats, a small colony of pallid bats, and a few individual big brown bats. The bridge over Guindani Wash has been serving as a roost for several different species (most notably Mexican free-tailed and pallid bats, with occasional use by others including cave *Myotis*). We have begun a program of evening bat exit counts of the bridge to monitor its use.

Dr. Ronnie Sidner and Ms Debbie Buecher, both of the University of Arizona, received an Arizona Game and Fish Department Heritage Fund grant to develop a call-library of southeastern Arizona bats. Kartchner Caverns was a primary study site for this work. They recorded a variety of bat calls (mainly from the cave Myotis, but also from other species) at the park using several different bat call analysis systems. These calls allow them to both better understand the call behavior of the bats and to build a library of bat calls that may help identify calls when the bat is not seen. Their report on the project will be completed sometime this year.

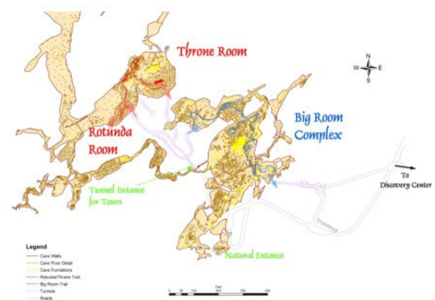
Dr. Karen Krebbs, of the Arizona-Sonora Desert Museum, completed her study of the possible effects of night military operations on lesser long-nosed bats (*Leptonycteris curasoae*) feeding behavior in southeastern Arizona. The park participated as one of the study sites. In the study they found that activity of *Leptonycteris* at the park was much lower in 2003 than it was in 2002; however, they also found that in other sites in the region (Krebbs and Hubbard, 2004). Although the decline may be a regional occurrence, it is important to take possible effects on nectar bats into account as we develop plans that affect agaves on the Park (such as landscaping and mowing).

Last year we worked with Dr. Warren Beck (University of Arizona Radiocarbon Laboratory) to have some cave *Myotis* guano dated at the University of Arizona facility. We collected a small sample of guano from the abandoned roost at the Keyhole (along the Big Room tour trail). We chose this roost because it appears to be some of the oldest guano in the Big Room. The result of the dating was that the guano was approximately 400 years old. This suggests that cave *Myotis* may have been using the Big Room for about the last 400 years. This is only one possibility, since we cannot be sure that we have sampled the oldest guano and we also cannot be sure that the bats have used the roost continuously for the last 400 years. The date does, however, begin to provide us with further information on bat use of the Big Room.

Geographic Information System and Databases

Activities and Observations:

- **A basic, but functional Geographic Information System exists for the park and cave.**
- **The GIS contains basic park infrastructure, cave natural and constructed features, and basic natural resource information about the park.**
- **Park monitoring data is up-to-date and stored in simple spreadsheets and databases.**



Over the last several years we have been working to develop tools to better track data about the cave and to improve analysis of the data. These tools have included a park Geographic Information System (GIS) for spatial data and simple databases and spreadsheets to track on-going monitoring and the results of scientific studies.

The park GIS contains a wide variety of spatial data vital to understanding the cave and surface environments. Information on the natural cave features includes the cave walls, ceiling features, floor features, formation areas, biological occurrences, geological features (faults, marker beds, etc.), hydrology, and paleontological sites. Constructed cave features in the GIS include trails (explorer and tourist), lighting system, communications system, and water system features (such as sumps and water spigot). Cave monitoring features are also included in the GIS; these include Environmental Monitoring Stations and microbial sampling sites. The GIS contains information on the natural features of the park as well including topography, geology, vegetation, archaeological sites, streams and drainages. Park infrastructure, such as roads, buildings, trails, wells, wastewater system, water valves, and propane tanks, are a vital component of system. These data were obtained from a variety of sources with a variety of accuracies. They are not integrated into a geodatabase structure. They will, I hope, be replaced with a better documented and integrated system as the GIS component of the Park Asset Management System is developed. However, until that that occurs, the park

GIS provides a vital tool for understanding and presenting data about the cave, park surface, and their relationship. **Figures 9, 10,** and **11** provide examples of the types of maps that can be produced with the existing park GIS.

Predevelopment and on-going monitoring data (such as cave temperatures, CO_2, radon, surface weather data, etc.) are stored in a variety of simple spreadsheets and databases. Most of the databases are maintained in Filemaker Pro. Although they are not complex or well integrated, these datasets are easy to update and analyze. They are kept up-to-date mainly by Cave Unit personnel or by the Science and Research Manager. Eventually, these data will be integrated into more comprehensive databases under the Park Asset Management System; however, the existing spreadsheets and databases provide a functional tool for cave study and management.

In addition to the monitoring databases, the park maintains a database of research reports and papers about the park. These are maintained in a Referencer v.5.2 database under Filemaker Pro. This database contains references to approximately 125 published and unpublished articles and reports concerning the cave and park.

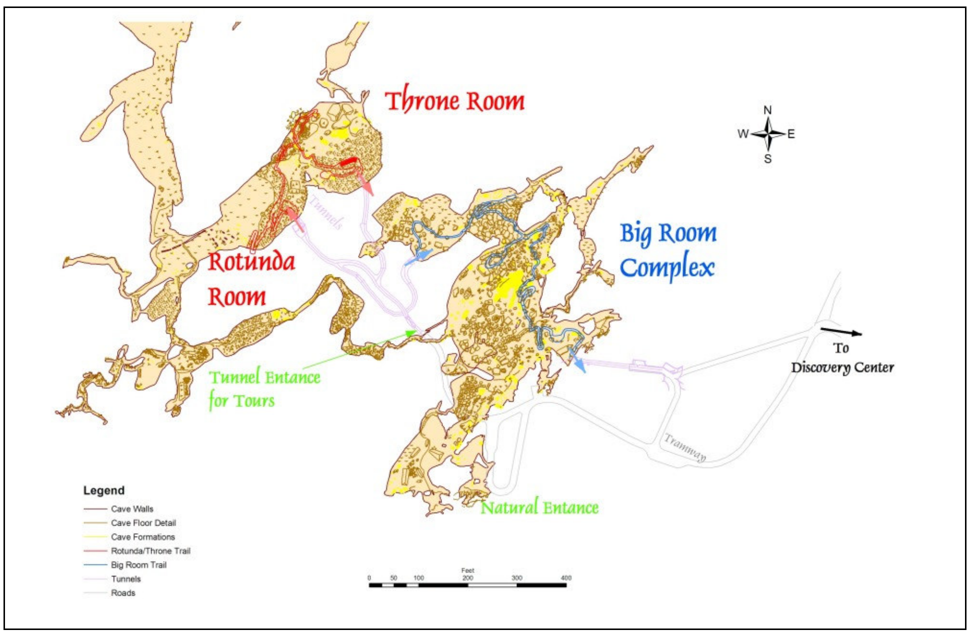


Figure 9 – *Map of Kartchner Caverns showing cave features, tunnels, tourist trails, and roads.*

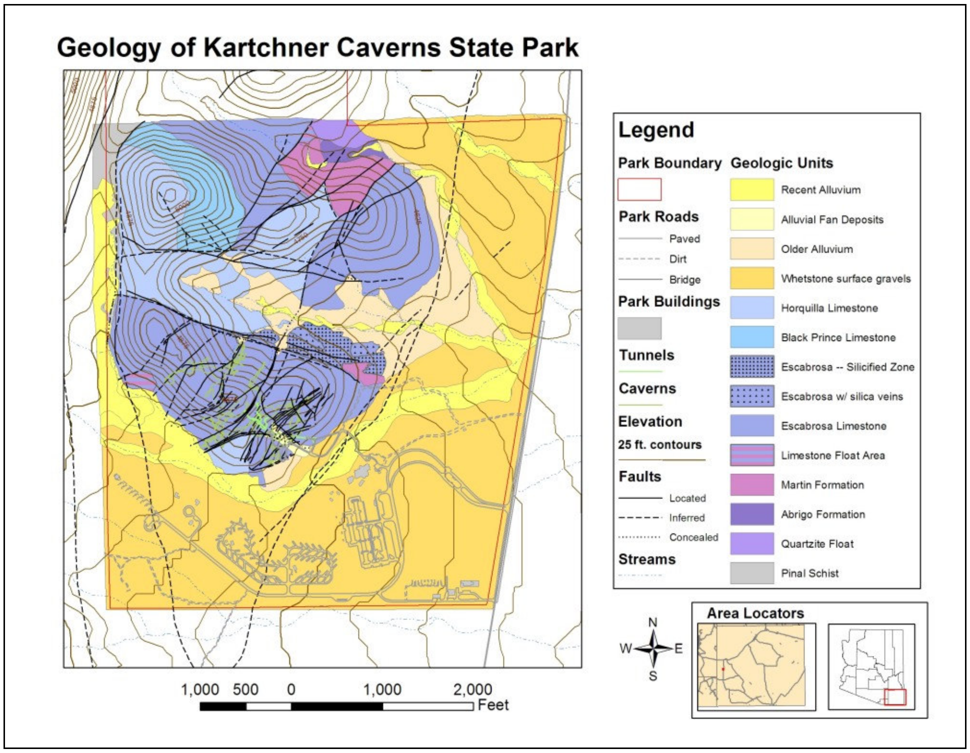


Figure 10 – *Map showing the geology of Kartchner Caverns State Park as mapped by Thomson (1990) including additional fault mapping from Jagnow (1999) and Shipmann and Ferguson (2003). in the showing cave features, tunnels, tourist trails, and roads. The map shows the relationship between the geology, cave, and infrastructure.*

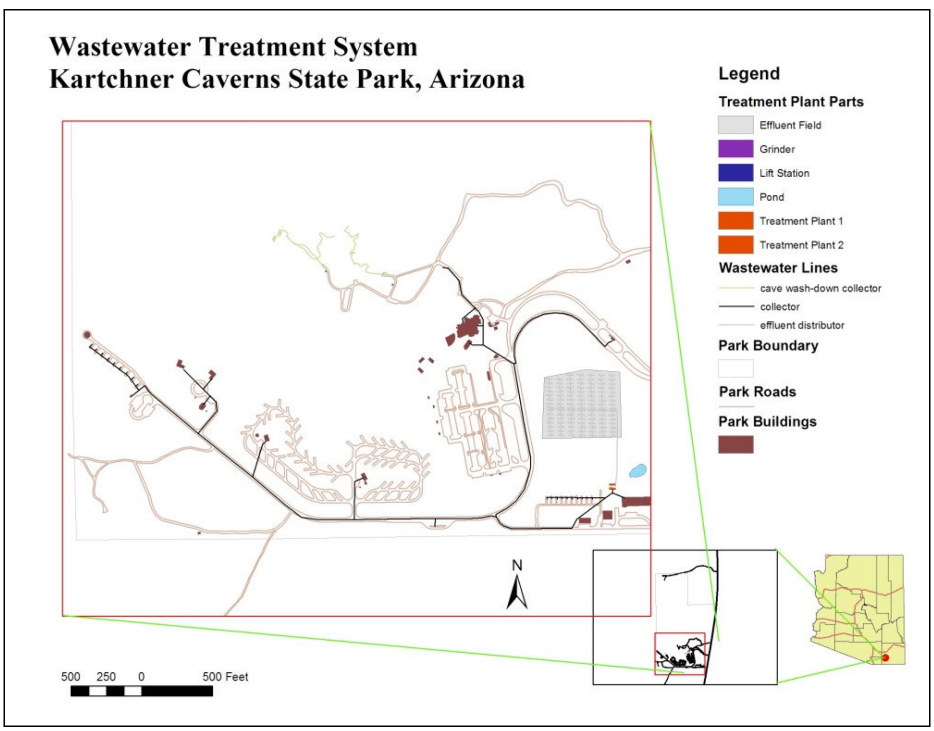


Figure 11 – *General map of the wastewater treatment system at Kartchner Caverns State Park. This map provides an example of GIS coverage of park infrastructure.*

Area Surface Land-Use Issues

Key issues:

- **Integration and protection of McGrew Spring.**
- **Mineral entry withdrawal proposal for Guindani drainage**
- **Land use changes near the park**

Rick Toomey on saddle overlooking McGrew Spring (Olson)

The 160 acre parcel containing McGrew Spring is now part of the park. Increased cooperative enforcement with the Border Patrol and more frequent clean-up trips have improved the environmental protection of the area around the spring. To fully integrate the parcel into the park, the two unfenced sides of the parcel should be fenced and signed to State Parks standards.

At the time of the writing of this report, the Coronado National Forest has proposed removing the Guindani drainage upstream from the park from potential mineral entry for a period of 20 years. This would be a strong protection measure that would help guarantee the quality of much of the water which flows into the cave from the Whetstones. We have been working with the Forest Service to better define the area requiring protection and refining the rationale for removing the area from mineral entry. State Parks should continue to assist the Forest Service in this effort.

Development in the Benson area has increased in area and intensity over the last several years. Range land is being converted to residential developments in the area between I-10 and the park. Although the most direct threat to the cave posed by development was mitigated by the condemnation of the area around McGrew Spring, the on-going development of the surrounding area should be carefully watched for evidence of impact on the park. Many potential impacts (mostly indirect) could result as development encroaches on the park. To better protect the park, we should seek to improve the buffers around the park. The most effective manner to do this would be to either acquire or protect two parcels of State Land around the park. The quarter section just east of the McGrew Spring parcel contains a small portion of the Kartchner Block. Although this section is almost certainly downstream of the cave, it would desirable to protect the entire exposed portion of the block. The section on the park's southern border may be even more important for the long term health of the park. That section contains a buried portion of the Kartchner Block. In addition, the aquifer from which the park draws its water extends into this section.

Inter-Agency Outreach and Cooperation

Key activities for year:

- **Worked with numerous governmental and non-governmental groups to improve management and protection of Kartchner Caverns and its resources.**
- **Worked with numerous governmental and non-governmental groups to improve management and protection of other caves, cave resources, and bats.**

Erin Fidler measuring air flow in blowhole (Toomey)

Over the last several years, we have continued cooperative and collaborative efforts with other governmental and non-governmental groups working on cave and bat issues. These efforts have include hosting field trips for a variety of land management seminars and meetings, participating in professional conferences, sharing expertise with private and public show caves that are planning renovations and retrofits, and meeting with representatives of federal and state agencies on numerous cave protection issues. The fruits of these collaborations should be evident from other sections of this report.

It is vitally important to the cave and to the agency that these efforts continue after I have left Arizona State Parks. The agency should not only remain open to collaborative work, but it should also actively seek out such collaborations. We must also remain engaged with the larger cave management community by participating in conferences such as the National Cave and Karst Management Symposia. Participation in such conferences will allow the agency both to provide data on Kartchner Caverns to other scientists and managers and to get information on new threats to the cave and techniques to mitigate or monitor them.

New Scientific Publication and Presentations

Key activities for year:

- **Publication (or upcoming publication) of at least nine scientific articles on studies at Kartchner Caverns.**
- **Two posters were presented at regional or national meetings on recent work at Kartchner.**

Extinct roadrunner leg bone from Tarantula Room (Toomey)

Articles

Carpenter MC and Mead JI, 2003, Late Pleistocene roadrunner (*Geococcyx*) from Kartchner Caverns State Park, Southeastern Arizona, *Southwestern Naturalist* **48(3)**: 402-410.

Cigna AA, Toomey RS III, and Nolan G, 2005, The Climate of Kartchner Caverns (Arizona, USA). Paper accepted for the 14th International Congress of Speleology, Athens, Greece, August 21-28, 2005.

Ikner LA, 2004, Assessing human impact of heterotrophic bacterial diversity in Kartchner Caverns – a culture-dependent study. University of Arizona, Master's Thesis, Department of Soil, Water and Environmental Science. 85pp.

Shipman TC and Ferguson CA, 2003, Geologic map of the McGrew Spring 7.5' quadrangle, Cochise County, Arizona. Arizona Geological Survey Digital Geologic Map. DGM-35.

Short MB, Baygents JC, Beck JW, Stone DA, Toomey RS III, and Goldstein RE, 2005 Stalactite growth as a free-boundary problem: a geometric law and its Platonic ideal, *Physical Review Letters* **94**, 018501: 1-4.

Stuckless JS and Toomey RS III, 2003, Long-term passive ventilation at Yucca Mountain: evidence from natural analogues. *Radwaste Solutions* **10(5)**: 31-37.

Toomey RS III, in press, Kartchner Caverns. IN (V. Hildreth-Werker and J. Werker, eds.) *Cave Conservation and Restoration.* Huntville, AL: National Speleological Society.

Toomey RS III and G. Nolan, in press, Environmental Change at Kartchner Caverns: Trying to Separate Natural and Anthropogenic Changes, IN *Conference Proceedings of Biodiversity and Management of the Madrean Archipelago II: Connecting Mountain Islands and Desert Seas*, USDA-Forest Service, Rocky Mountain Research Station.

Turner DS, Holm PA, Wirt EB, and Schwalbe CR, 2003, Amphibian and reptiles of the Whetstone Mountains, Arizona, *Southwestern Naturalist* 48(3): 347-355.

Posters

Ikner LA, Neilson JW, Toomey RS, Maier RM, 2004, Assessment of Human Impact on the Culturable Microbial Diversity of Kartchner Caverns. Poster presented at the 104th General Meeting of the American Society for Microbiology. May 23-27, 2004, New Orleans, LA.

Toomey RS III, Travous KE, Ream JP, and Nolan G, 2004, Kartchner Caverns State Park: Approaches to Protecting a Delicate Environment during Development and Tours, Poster presented at Connecting Mountain Islands and Desert Seas, Biodiversity and Management of the Madrean Archipelago II, Tucson, AZ, May 11-15, 2004

The Future

Overall the state of the cave is healthy. Although temperatures are up and humidities are down, it is clear that at least some of that trend is related to regional climate change. Unfortunately, the extent to which development plays a role in the changes may not become clear until regional drought conditions ease for several consecutive years. Bat populations on the park continue to thrive. New and on-going scientific studies will allow us to better understand the cave and its management issues. Some of the studies are even revealing fundamental information about how caves function. The microbial flora of the cave has certainly been affected by development. This is one reason why visits are limited to the undeveloped portions of the cave. Preserving the less impacted environments will allow rarer ecosystems (such as the natural cave microbial ecosystem) to survive in spite of development. We can also help protect these ecosystems by monitoring the changes caused by development to better understand them. The cave staff (interpretive and cave unit; professional and volunteer) continue to protect the cave as the interpret it.

There have certainly been many changes in the cave since it was discovered. Some of those changes are natural; others relate to development and tourism. Arizona State Parks must remain vigilant in trying to determine what changes are related to development and in trying to mitigate those changes to the extent possible. To do this they must remain committed to the goal of operating the cave in such a way as to minimize the impacts on it. Impacts are unavoidable in developing and showing a cave. We must strive to be sure that our visitors get sufficient return for the impacts they inevitably contribute to by continually improving the quality of our tours.

References Cited

Krebbs K and Hubbard T, 2004, *Habitat Use by the Endangered Lesser Long-nosed Bat (Leptonycteris curasoae) along Military Routes in Southern Arizona,* Final report prepared for Luke Air Force Base under contract DAMD 17-01-2-0065. Arizona-Sonora Desert Museum.

Cigna AA, Toomey RS III, and Nolan G, 2005, The Climate of Kartchner Caverns (Arizona, USA). Paper accepted for the 14th International Congress of Speleology, Athens, Greece, August 21-28, 2005.

Shipman TC and Ferguson CA, 2003, Geologic map of the McGrew Spring 7.5' quadrangle, Cochise County, Arizona. *Arizona Geological Survey Digital Geologic Map*. **DGM-35**.

Short MB, Baygents JC, Beck JW, Stone DA, Toomey RS III, and Goldstein RE, 2005, Stalactite growth as a free-boundary problem: a geometric law and its Platonic ideal, *Physical Review Letters* **94**, 018501: 1-4.

Thomson KC, 1990, *Geology of Kartchner Caverns State Park, Cochise County, Arizona*. Unpublished report to Arizona Conservation Projects, Inc. 37 pp. and 24 map sheets.

Toomey, RS III, 2003, *Kartchner Caverns State Park Environmental and Research Report 2003*. Report Submitted to the Arizona State Parks Board, October 1, 2003. 33pp.

Toomey, RS III, 2002, *Cave Resources Manager Annual Report 2001-2002*. Report Submitted to the Arizona State Parks Board April 18, 2002. 19pp.