ERRATA

Subsurface Management Plan

Oregon Caves National Monument

The following Errata must be attached to the Environmental Assessment (EA) in order to comprise the full and complete record of environmental analysis for the Subsurface Management Plan for Oregon Caves National Monument.

Written and Verbal Comments

Comments from letters in response to the EA or to issues outlined in the EA are itemized in these Errata, which amend the EA. National Park Service (NPS) responses are provided to each comment.

Numerical Breakdown of Responses of Individuals Recommending Alternatives

Alt. A	Alt. B	Alt. C	Alt. D	Alt. E	NOTA	Misc. +	Misc. -
	2		13		4		

Definitions

NOTA: none of the above, i.e., none of the listed alternatives are acceptable

Miscellaneous +: Five individuals expressed interest and/or support for a caving tour, but did not comment on the EA.

Comments below are divided into categories. Pertinent comments from previous environmental assessments have been added. Park responses are italicized.

COMMENTS FROM PARK STAFF

One park employee has stated that past monitoring has impacted bats to the point of causing substantial mortality.

Park Response: *There is no scientific evidence or expert opinion from cave bat monitors that increased mortality or other potential impairments have resulted from past inventory or monitoring of bat populations in Oregon Caves. Only two dead bats have been found in Oregon Caves since 1988, and apparently neither was the result of monitoring. One was found in 1990, a time prior to cave bat monitoring. The other was discovered in spring of 2006 on the cave side of the exit tunnel airlock. It is thought to be a bat that was seen unmoved on a ceiling seven feet above the paved tour route several weeks after tour season began. Bat census data from winter 2001 to winter 2004 indicate that the greatest impact on the number of bats in the cave is the opening of the cave to public tours (2-15 people) that are given three to four times a day in mid- to late March (fig. 1). Surface temperature also has an effect (figs. 2 - 3).*

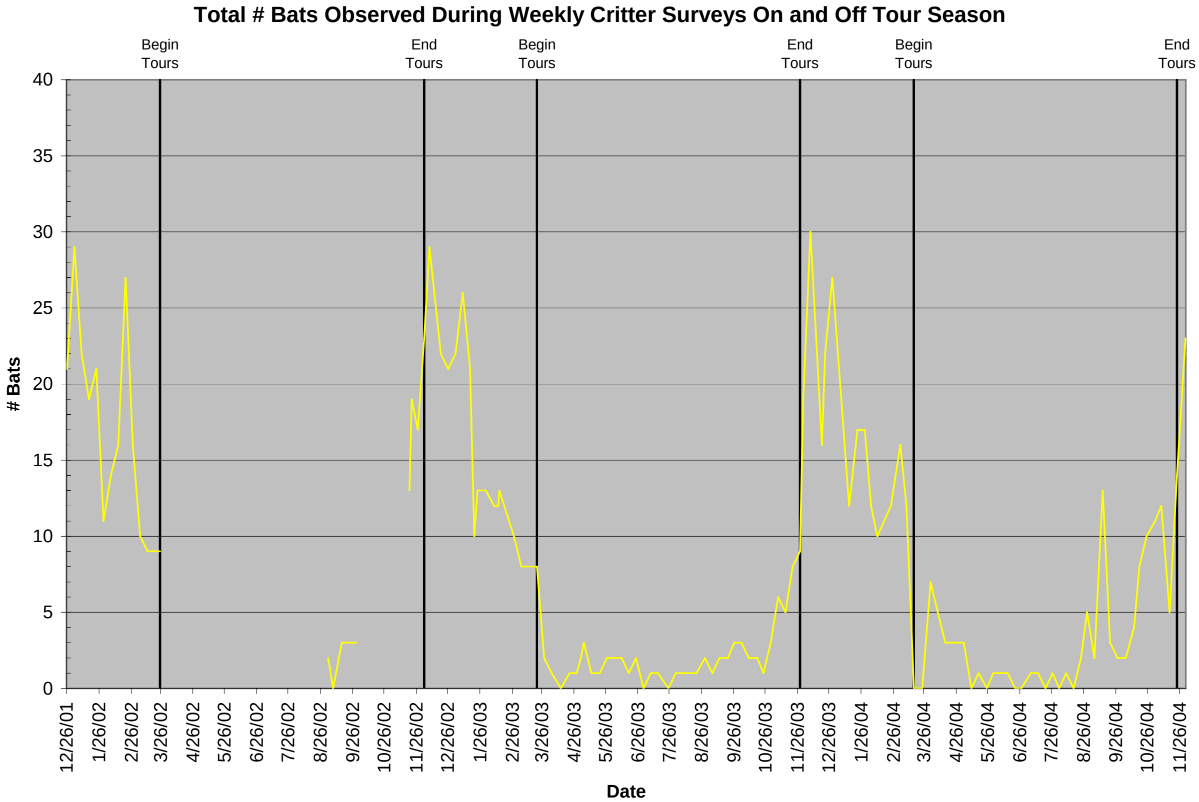

Figure 1 *Graph of tour season and bat counts*

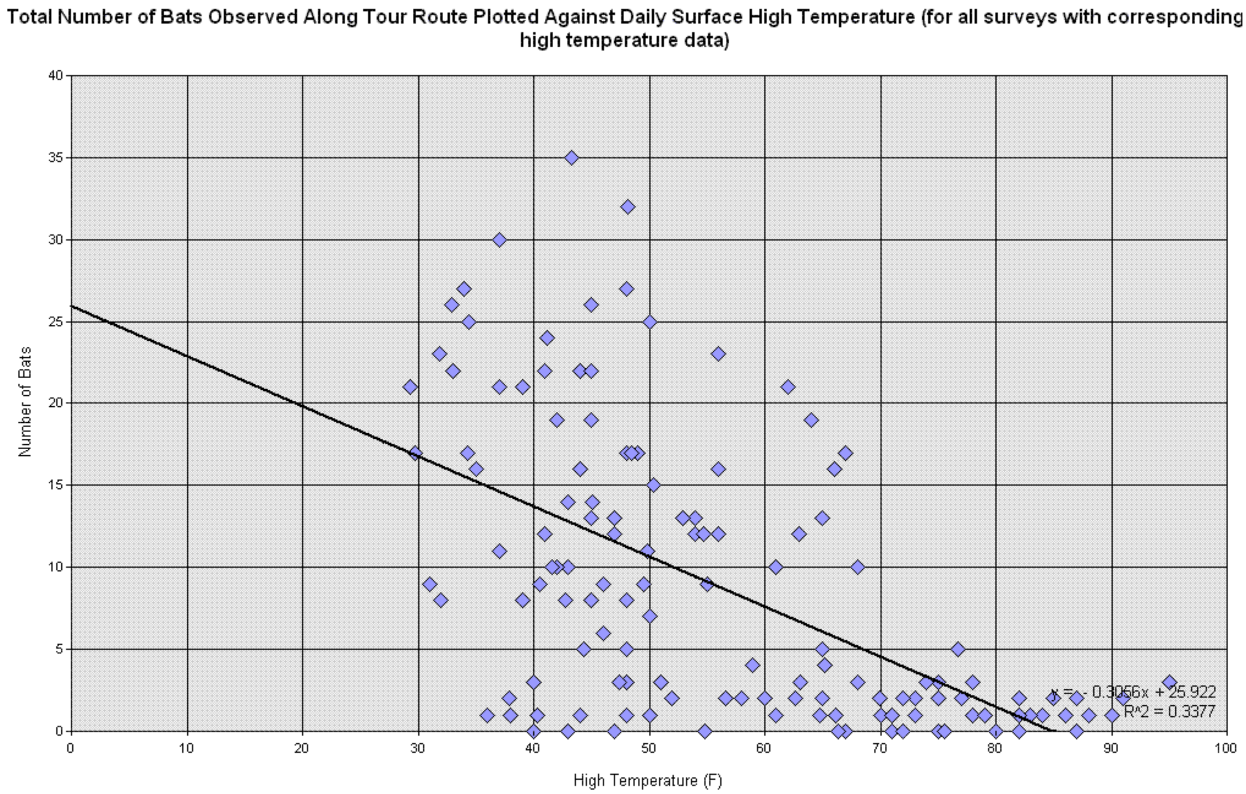

Figure 2 *Scatter plot of daily surface highs and bat counts*

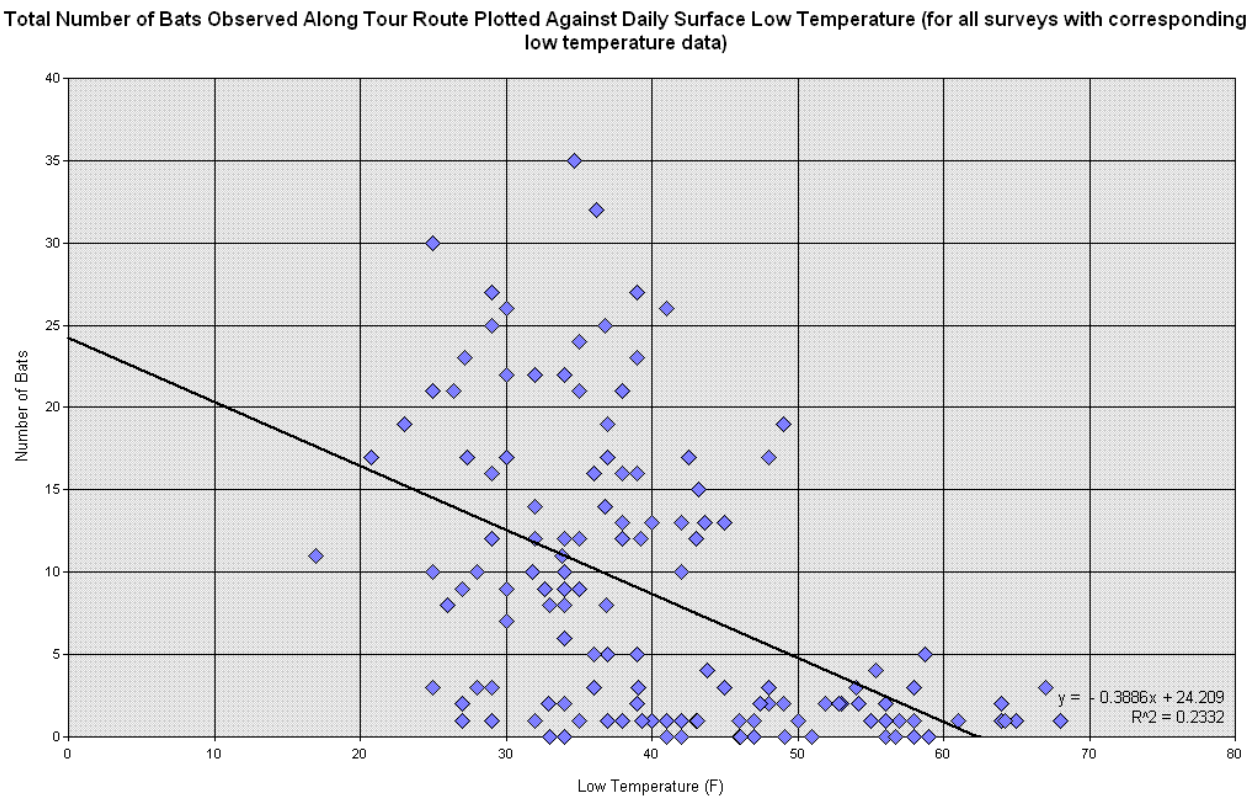

Figure 3 *Scatter plot of daily surface lows and bat counts*

The likelihood that the absence of observed mortality results from disturbed bats flying out of the cave in winter and dying where they are not counted is very low from an ecologic and evolutionary viewpoint. If the sound of footsteps on a smooth paved trail wakes a substantial number of bats from hibernation, then the sound of dripping water is likely to do so as well, reducing the value of hibernation as an evolutionary and ecologic strategy to zero. Likewise, the added heat from one or two individuals is far less than that from natural diurnal cycles. Most disturbances probably occur from increases in light levels. The weight of expert opinion is that red light likely has less impact on bats than white lights. Therefore, red lighting will be used in Oregon Caves for bat census surveys.

Bats visible from the tour route appeared to have increased in number after the gates were modified in 1992 to be more bat friendly. Bats did increase after winter tours were discontinued, but modifying the gates a few years earlier may have also increased their numbers. Without adequate monitoring, it is hard to statistically separate out the two apparently causative factors, especially since we are talking about small numbers of bats in any case. The number of bats visible from the paved route (almost all Townsend's) range from a few to up to 35 bats (the average of all surveys conducted is almost nine) with an average distance to the trail of about 15 feet.

Bat counts have been conducted on an approximate weekly basis on- and off-season since December 2001, though there are notable gaps during tour season in 2002 and for most of 2005 (fig. 4). Now that an initial baseline has been established, the monitoring schedule will be reduced this winter to one person on one visit per hibernation season. This is in the low range of monitoring frequencies suggested by seven cave bat monitoring experts and in accord with the Bat Conservation International (www.batcon.org) recommendation that winter surveys of hibernacula sites be conducted no more than once every 1-2 years. More frequent monitoring is unlikely to add much additional information to the strong association of low bat numbers with the start of public tours, the weak association with high outside temperatures, and the possible association with monitoring frequency. Based on the baseline information, this once-a-year frequency of the hibernation season of late October to late March is likely to have fairly minimal impact. This assumes that the survey is done by one person with an ambient non-focused red light and sneakers making minimal noise while passing by each bat site in less than a few minutes and staying in the middle of a paved trail.

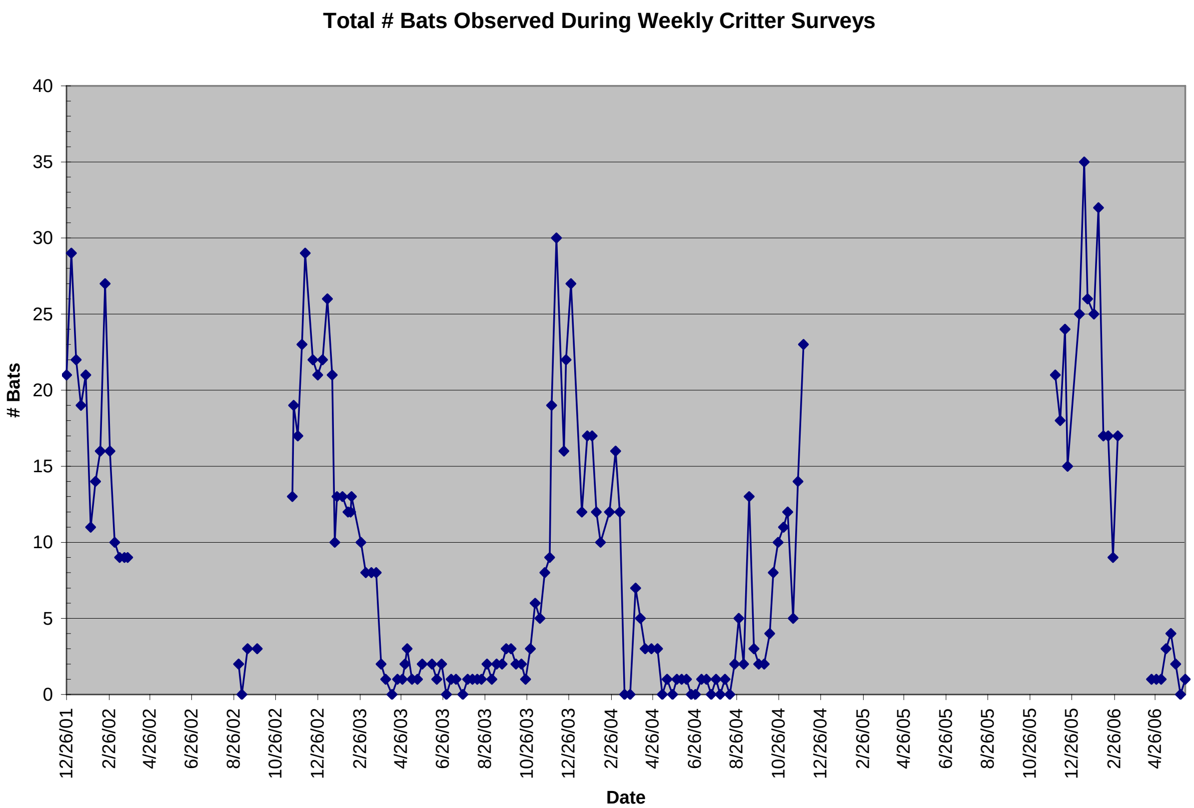

Figure 4 *Total number of bats observed during weekly biologic surveys*

Comments from the Public and Non-governmental Organizations

GENERAL COMMENTS

Several commentators said that more baseline studies should be initiated. One commentator said that the difference between "baseline" and "inventory" should be more discernible. Another commentator said that baselines should only be those where there are no previous human impacts.

Park Response: *A baseline is generally a stand-alone inventory or the first phase of a monitoring program. Ideal baselines are established with minimal human impacts, as the main reason for baselines on NPS lands is to assess the degree of future human impacts. However, previous human impacts exist in most habitats. An exception is deep subsurface area isolated from surface water and air. Therefore baselines often must be established in spite of pre-existing impact.*

Based on comparison to other caves with known visitation rates and the professional judgment of experienced cavers, all parts of the proposed caving route had been traveled by at least a thousand people prior to a trial run in 2001. Therefore, some baseline studies can be done in the first year of caving tours because additional environmental impact of the number of people on the route during that length of time almost certainly would not be measurable.

Baseline studies that have been completed or will be completed before the proposed start of caving tours include bat monitoring with Anabat II detectors, DNA studies, and radon monitoring. Impact mapping of both the proposed caving route and the main trail will utilize a modified version of mapping criteria used by Bunting & Balks (2001) and Bodenhamer (2005). A plan to measure the amount of discoloration on white speleothems and relate it to distance from the trails was dropped due to the inability to eliminate confounding factors such as uneven shape and varying wetness of surfaces. Added to the impact survey will be sediment porosity sampling, which will see whether a penetrometer can be used as a proxy for measuring sediment compaction. A cultural affiliation study will be completed by the end of September 2006. Except for more biologic inventories (see below), no other studies have been suggested by the various *respondents as a way to complete baseline studies. It is not clear what additional research could be conducted along the proposed caving route to inventory baselines that would yield useful information other than past or ongoing studies and studies proposed in the EA and these errata to measure future impacts.*

It is not possible to conduct complete biologic or other studies without further impacting the cave or jeopardizing the integrity of future studies that may be conducted with advanced and less damaging technology and techniques likely to be developed in the next few decades. Funding of any monitoring or inventory project at Oregon Caves is largely contingent on the magnitude, scope, and scale of actual or possible impairment threats to park resources and the urgency and feasibility of mitigating or preventing such threats. A formula that could comprehensively help resource managers decide whether to monitor something might be the sum of (1) whether the potential or known intensity, extent, or duration of an impact will likely cause impairment, (2) whether we might in the present or future be able to do something to reduce the human-caused impact if we had more data, and (3) whether we are likely to get useful data that addresses 1 and/or 2 divided by (4) cost in time, money, and impact on resources. We consider some of these factors when writing PMIS statements, EMS plans, inventory and monitoring plans, and in approving or disproving collecting permits, but rarely do we combine these in justifying whether or not to pursue a particular course of action. Whether or not some formula is adopted, there should be more discussion in the plan of impacts from our monitoring efforts. Sometimes the only way to get the information you want involves so many repeated trips to caves that the impacts, safety, and economic costs are not worth it. Therefore, any proposed study to monitor human impacts will need to be weighed for its effectiveness in answering impact questions versus *the effectiveness of other studies and projects that seek to monitor what likely are more serious human impacts and/or mitigate or prevent human impacts both in the cave and on the surface of the Monument. A watershed assessment from the summer of 2006 to 2008 will address some of these concerns by relating impacts above ground to human impacts underground, such as changes in vegetation as a result of fire suppression or climate change. An extended discussion of monitoring vital signs for caves and at Oregon Caves is found in an appendix attached to these errata.*

Two commentators pointed out that Oregon Caves is a small cave and therefore more susceptible to damage than other NPS caves. Another commentator said that the proposed caving tours should not be allowed so that one could avoid or minimize potential impacts to park resources. This is similar to another comment that the public should be allowed to use national parks only if use does not interfere with resource protection.

Park Response: *Under this reasoning, all humans should be excluded from parks, as every park staff member or visitor to a park has some impact on park resources, and therefore interferes with resource protection. This was not the original intent of the Organic Act nor is it in the subsequent legal rulings and other governmental interpretations of that Act. NPS surveying, inventory, monitoring, and restoration actions, placement of the proposed caving route, level of park ranger supervision, and training content for both park rangers and visitors have been designed with the main intention of avoiding or minimizing potential impacts to park resources to the point of being reasonably certain that no impairment is taking place.*

It is the policy of the National Park Service to encourage a diverse set of opportunities to experience caves as long as such opportunities do not lead to significant net impacts on park resources. Other NPS areas have given guided caving tours in caves smaller than Oregon Caves, e.g., Great Basin National Park and Carlsbad Caverns. However, comparing tours in Oregon Caves to tours in other park-managed caves is of little value. What is important is the potential impact of tours to Oregon Caves as a whole. Although much of the rest of the cave is well decorated, the proposed caving route was specifically chosen because of the lack of easily damaged speleothems. Prospective cavers on public tours would be trained in both safety and caving ethics similar to those stated by Hildreth-Werker & Werker (2005). Less than one percent of the cave would be affected by shoes or brushing up against a low ceiling on the paved route and proposed caving tour.

Oregon Caves is a significant cave which offers the public diverse opportunities to experience the world underground. The National Park Service does not consider Oregon Caves a sacrificial cave, but rather a special environment in which the public can learn to appreciate caves as well as learn caving and resource protection skills.

One commentator said that a caving tour should not go to the South Room, as that area was furthest from the main paved trail and therefore likely to be the most pristine part of the cave.

Park Response: *The South Room is not most pristine part of the cave. Other rooms with smaller entrances have been traveled less often.*

One commentator stated that the park should be following the Franklin Lane NPS policy guidelines of 1918.

Park Response: *These guidelines have been superceded by more recent guidelines.*

One commentator said that lint and dust generated by caving groups should be cleaned periodically.

Park Response: *Based on studies at Carlsbad Caverns and the amount of lint collected at Oregon Caves, the quantity of lint generated by the number of people on caving tours per year would be minute (less than a quarter of an ounce). Because of the wet nature of the proposed caving route, the movement of dust would also be miniscule and not measurable. In addition, approximately half of the lint decomposes in the high humidity in the cave (that composed of organic fibers), thus preventing periodic removal of that part of the lint that likely has the most biologic effects.*

One commentator stated that the surveying and mapping standards should be simplified so that it can be more efficiently completed.

Park Response: *This is a valid point that will need to be addressed before any substantial amount of surveying takes place in the Monument's underground. Such changes in surveying protocols do not rise to the level of these errata because of the miniscule changes in impact, but the protocols should be revised so as to reduce the time surveyors stay in the Caves and thereby* *reduce total impact, while maintaining the appropriate degree of accuracy and data management. Guidelines for doing so are outlined in Seiser (2005).*

GEOLOGY COMMENTS

One commentator asserted vandalism would take place on guided tours. Another commentator said that the terms vandalism, mutilation, and defacement should be defined.

Park Response: *The proposed caving tour was designed to minimize the potential for both deliberate and inadvertent damage to park resources in its location, the maximum number of people allowed (six), and the use of two park guides for each tour. As far as can be discerned, there has been very low vandalism in off-trail park caves, such as at Carlsbad Caverns National Park, where there are no park guides. There are almost no known cases where significant vandalism occurred within the sight of a park ranger in any park.*

Therefore, it is highly unlikely there will be any significant vandalism at Oregon Caves, which has better monitoring systems and tour oversight than nearly any other cave. Tour guides and visitors would prevent individuals from causing extensive/ significant damage in any one locality. Vandalism could conceivably be spread out along a tour, but impact mapping done every three to six years would detect such vandalism, and the tours would be stopped before continued vandalism rose to the level of impairment.

NPS agrees with the commentator about the definition of the three terms. There have been a few cases of vandalism along the paved route, meaning deliberate or malicious damage. Mutilation *(irreparable injury or damage) seems more appropriate for accidental breakage, collecting souvenirs, etc. The use of the term defacement (to mar the surface or appearance) would be more appropriate for writing by tourists and cavers, incremental wear, tear, discoloration, and other skin-deep alterations, some of which are repairable.*

BIOLOGY COMMENTS

Concerns were expressed about the impact of public tours and restoration/mitigation projects on bats.

Park Response: *The modifications to the proposed alternative B would eliminate all restoration efforts in areas with more than two bats during the winter season when they are most sensitive to disturbance. The impacts that occur during restoration or mitigation on-season should be held to a minimum, taking precautions to avoid such work when there are concentrations of bats near the trail. However, some impacts may be unavoidable. Minor impacts such as potentially causing a single bat or two to fly away from the disturbance may be allowed if the mitigation is substantial, such as installing tarps to trap human-caused organics and prevent those organics from spreading further into the cave.*

The brightness of flashlights used by cave guides has been substantially reduced both to lessen potential impacts on bats and macroinvertebrates and to maintain the night vision and safety of visitors who might lose their night vision after seeing a highly illuminated formation or being accidentally caught in the direct beam of a bright flashlight. Recent literature such as from Mann et al. (2002) and Elliott (2005) will be reviewed to determine whether there needs to be *further restrictions on the use of flashlights by cave guides or whether any inventory should be conducted during hibernation of at least some bats.*

The last completed bat survey by Dr. Steve Cross suggests that bat populations are now similar to projected population levels of the1970s and 1980s instead of the lower count of 1995. The latter low count may have been due to the shift of bats' use from the Exit Tunnel to the 110 Exit. This will need to be followed up with more research to determine whether or not putting an additional air restrictor in the Exit Tunnel to restore cave airflow will substantially affect bats that use the cave both in winter and during fall swarms. It is unlikely that the relatively dim lights used by caving tour participants will greatly affect any bats that might be present. Further studies by Dr. Cross will monitor more portions of the proposed caving route, but all available evidence so far suggests that significant numbers of bats do not use the proposed route during the time of the year that the tours are conducted.

One commentator stated that a biological study needed to be done, such as the recent compilation of invertebrate records at Sequoia-Kings Canyon National Park.

Park Response: *Due to the potential impact of collecting and the impossibility of completely adequate sampling, a complete biological study is not feasible in this cave or any cave. A list of known species was included in the draft subsurface management plan. Although it needs to be updated to include 19 more species of fungi and bacteria identified in recent DNA studies, this list already has more species than have been compiled for any other cave in North America, except possibly Mammoth Cave.*

PALEONTOLOGY COMMENTS

Two commentators pointed out that more surveys of fossils were needed, as there is very little prior information on the fossils, and some fossils are under heavy rubble that could destroy bones if stepped on. Another commentator stated that the age of the grizzly bear bone that was radiocarbon-dated was in excess of 50,000 years, not dated at 50,000 years.

Park Response: *The grizzly bone was successfully dated by radiocarbon and was found to be in excess of 50,000. This is one of only two grizzly bones in North America that exceed 35,000 years of age. A radiocarbon date for one the jaguar bones was 38,600 years.*

A review of seven samples from the cave route by Dr. James Mead completed in the summer of 2002 revealed small, insignificant amounts of bone in sediments walked over on the proposed caving route. One site yielded a Peromyscus species (deer mouse) and unidentifiable bat remains. Another site yielded scrap bone material from bats and a partial maxilla and dentary of Cleithrionomys species (vole). A third site had an unidentifiable bone scrap. There were no bones detected in the three other samples. The presence of bones is not surprising since so many—if not most—sediments in the cave appear to have bone material (at least fifty sites, and likely more). None of the bones were considered significant for their paleontologic value. Therefore, it is unlikely that being too close to the surface will damage any bone resource in either significant numbers or value. The amount of bone material along the proposed re-routing of the cave tour appears so small that someone inadvertently breaking the hardened surface of the trail by twisting a shoe might impact at most one or two bones. Little evidence of such *breakage has been found, and no broken bones have been found. A small amount of rubble is traversed, but it is in apparently fossil-free locations or is of such large size that it is very unlikely that rocks would be moved that could damage bones underneath the rocks. Further sampling could give better estimates of bone concentrations but could not determine the possibility of bone breakage. Further sampling would mainly expose more bones to possible damage.*

Visitors on the path of the proposed re-routed caving tour are not creating a new human impact, as this area of the cave has been regularly traveled over the past 70 years. Pre-caving instructions from cave guides to groups and flagging along the caving tour route will reduce the spread of compaction when moving through the cave. The amount of future compaction from the anticipated number of cavers on the proposed caving route is expected to be insignificant and likely not measurable.

In conjunction with Ted Fremd, the Chief Paleontologist at John Day Fossil Beds, the monument will develop a paleontology plan in FY 2007 that will cover the monitoring and curation of paleontologic objects from the monument.

Additionally, a comprehensive archeological survey covering the Monument surface and caves was completed in September 2003. No artifacts or other evidence of Native American use of the Monument were found.

SAFETY COMMENTS

One commentator was concerned about the safety of having an extended caving route that involved crossing irregular breakdown with slippery surfaces.

Park Response: *Whether a surface is slippery is a subjective assessment. Most such surfaces are found closer to cave entrances where additional organics provide a substrate for microbes that can add slickness mostly through various types of sugars and other substances produced by bacteria or fungi. Anecdotal data on accident rates of park-guided tours off paved trails suggest that they are less common per person hour compared to the accident rates of tours on paved trails, perhaps because most people are extra careful if there are irregular surfaces to walk on. Even though the possibility of falling along the cave route may be higher than on the main paved trail, this discrepancy can be largely mitigated through careful training of visitors and guides and the amount of supervision by park rangers while traversing the cave. By rerouting the proposed caving trail, the removal of a "step-across" above a pit should reduce the possibility of major injuries should a slippage occur.*

CULTURAL COMMENTS

A commentator recommended increased recording of the historic signatures. Commentators on a previous EA suggested that caving tours could damage cultural resources.

Park Response: *No effects on cultural resources are anticipated because no significant cultural resources that could be substantially impacted are known to be present in the Caves. There is wear on the historic marble steps in the cave, but the installed grate platforms probably removes* *most quartz grains involved in such wear and tear. Based on past wear, the steps should last for several centuries but may eventually have to be replaced in kind. An ongoing cultural affiliation study will better document historic and contemporary tribes (peoples) that are or can be associated with a park. It is difficult to see how additional work with historic signatures would help the park better protect the subsurface. However, such a study would be done with a volunteer with the appropriate photographic and inventory skills.*

One commentator stated that the exclusion of large individuals from the caving tour could lead to a discrimination lawsuit.

Park Response: *Oregon Caves is dedicated to improving access for all visitors, as the recently built administration building and planning for renovation of the Chateau demonstrates. However, the only way to allow large individuals or those with some degree of claustrophobia on a caving tour would be to enlarge crawlways by removing a great deal of rock, thus significantly damaging the Caves. This is not reasonable accommodation.*

AIR QUALITY COMMENTS

Concerns were expressed by two commentators that more radon studies were needed to assess the health risks of the proposed alternatives. One commentator suggested that with a carbon dioxide level of greater than >1%, CO2 poisoning was a real concern.

Park Response: *A survey from July 1, 2002 to November 1, 2002 showed an average of 49.0 picocuries (pCi) per liter in the South Room and an average of 66.0 pCi/liter in Kincaid's*

Dancehall. The industry–accepted and Environmental Protection Agency recommended conversion factor from pCi/liter to working levels is 4.0 pCi/liter = .02 working levels). That results in a .245 working level for the South Room. A working level (WL) is defined as any combination of the short-lived radon daughters in one liter of air that results in the ultimate release of 1.3x105 MeV of potential alpha energy. To exceed the current NPS standard of four working level months per year, a person would have to spend 2,775 hours per year at the South Room's level of exposure during the time of cave tours (July to early September). The average time each park ranger spent on the cave route in the summer of 2001 was less than 100 hours. The South Room concentration is close to the 41.75 pCi/liter average of the 20 sites surveyed along the paved tour route and proposed caving route. Therefore, caving guides would not be exposed to any more radon than if they were conducting regular tours on the paved trail.

These radon concentrations are similar to those determined in the 1970s and even more similar to radon concentrations determined by Dr. Aley when he put temporary airlocks in the same locations in the late 1980s as permanent airlocks were installed by the park in 1990. Therefore, it is unlikely that circulation has been restricted so as to reduce radon concentrations in the main cave.

Carbon dioxide instrumentation has never detected concentrations of carbon dioxide in the proposed caving route approaching 1% carbon dioxide. Conditions that usually produce high carbon dioxide levels, such as dissolution by sulfuric acid or large amounts of flood deposited organics are not present in Oregon Caves. Symptoms of carbon dioxide intoxication have never been observed in people traveling through Oregon Caves. A new once per month carbon dioxide *survey at all Hobo sites (temperature and humidity) in the cave will be conducted starting in August of 2006.*

VISITATION COMMENTS

One commentator suggested that the ratio of park rangers to visitors on a caving tour should be one to two. One commentator expressed concern that the preferred alternative was overbalanced in favor of public use versus protection of resources, as emphasis on the former would seem to intensify wear and damage to the caves.

Park Response: *The proposed lantern, geology, and caving tours do not significantly increase the number of visitors to the cave. The regular 7:00 p.m. tour (maximum 15 visitors) will be replaced by a lantern tour with a maximum of 12 visitors. The proposed caving tour will have a maximum of six visitors. That is an increase of only three visitors per day for approximately 75 days during the busy summer season. Overall numbers of people in the cave have decreased from about 116,240 in 1976 to 53,157 and 57,189 visitors in 2002 and 2001, respectively. The difference with the addition of the caving tour would be an insignificant and not measurable amount of further compaction within flagged areas, whereas the reduction of visitors on the paved trail likely would reduce the amount of shoe material scraped off on the rough paved surfaces.*

The park continues to improve and adapt training for cave guides to provide them with the best preparation and knowledge for giving cave tours and educating the public about the natural and cultural history and conservation of caves.

However, no national park could operate under a standard for which every visitor must be monitored constantly to ensure that no resource impacts occur. Even if the guide-to-visitor ratio was 2 to 1, guides could not always see what the visitor would be doing at every moment. Furthermore, it is not necessary for the guide to always keep an eye on the visitors for two reasons: first, with proper techniques, visitors would learn proper caving etiquette, and the tour would move slowly enough to give each visitor time to move carefully along the tour route; second, there are very few formations that can be damaged on either the paved route or the proposed re-routed off-trail caving route.

APPENDIX A
Monitoring Vital Signs for Caves at Oregon Caves

Inventory and recurring, long-term, scientific research can be difficult to distinguish from monitoring, and these activities often overlap. A project that begins as an inventory or recurring scientific study may become a monitoring project. Also, many of the techniques used in monitoring are also used in inventory. For example, most of the same instruments used to measure cave climate, water quality, or visitor impacts are used to make an inventory of the same parameters. It is important, then, to clarify the separate goals of each of these three activities.

Vital signs are selected physical, chemical, and/or biological elements and processes of park ecosystems that represent the overall health or condition of the park; they may also be park attributes that are highly valued though not necessarily indicative of general park health. An inventory is conducted to determine what vital signs need to be monitored and the initial state of a vital sign, cave, or cave resource. Inventory is also necessary to choose appropriate places to monitor, to determine what monitoring techniques are most appropriate, and to establish the initial conditions from which the monitoring will take place. Inventory is a crucial prerequisite and companion to monitoring.

Recurring, long-term, scientific research is more difficult to distinguish from monitoring. An example of recurring scientific research might be a study of dissolution rates of limestone in a cave passage. Such a study would involve taking measurements of a parameter such as weight of a limestone plate or the retreat of a wall from a set point at regular interval using a set protocol. In that way the activity would be the same as monitoring. However, monitoring should have the potential to influence management action. That is, it should be measuring a parameter that is likely to be affected by possible management actions and which will show a change if management actions are altered. A study that starts as a recurring, long-term scientific study may become a monitoring project as understanding of the impacts of management actions and the process being studied changes. Monitoring projects may also contribute data that can be used for scientific studies that seek to understand cave processes. Indeed, as one implements a monitoring project, it is important to try to set it up in a way that provides as generally useful data as possible.

The focus of monitoring efforts should be on processes that management actions are likely to impact in terms of restoration, mitigation, prevention, etc. However, the effect of global warming and increasing carbon dioxide is likely already having a significant effect on cave microclimates, speleothems, and speleogens, although we have not yet done enough monitoring to know the severity of the impact. So how can we prioritize our monitoring efforts if we do not know what substantial human impacts are and whether or not they might someday rise to the level of impairment? In other words, the only way we might be able to do something to mitigate the impact of global warming and carbon dioxide increases, such as changing entrance sizes or prescribed burn plans, is to know more about the effect of global warming and atmospheric carbon dioxide increases on our caves via inventory and monitoring. Therefore, we shouldn’t disregard monitoring a particular impact just because at present we cannot see exactly what we can or should do about the impact or because we think we know that we cannot do anything about it. Monitoring sediment carbon dioxide solution rates via calcite slabs nearly identical in shape and weight is rather inexpensive. There is also value in being a witness to major impacts even if we can't directly and/or quickly reduce those impacts. Perhaps our visitors will if they get a strong enough message from the parks backed by science.

Caves are found at the interface of the geological, hydrological, biological, and atmospheric realms and disciplines. Many of their resources and processes cannot be readily separated into simple categories. For example, evidence in increasing of microbiological roles in some speleogenesis (cave formation) and mineral deposition (Barton and Luizer, 2005; Barton et al., 2001; Northup and Lavoie, 2001). Are these microbiological processes best considered biological, geological, both, neither, or something in between? Cave climate, although probably best considered as an air resources issue, has very profound effects on many aspects of caves and on cave resources. In fact, it may be the single most important aspect of many caves to monitor for resource protection as may be the case with Oregon Caves. Other major vital signs can also provide important information for managing caves as a whole or important geological resources within them.

VITAL SIGN: CAVE METEOROLOGY

Cave meteorology refers to the microclimate and air composition of the cave and includes air temperature, water vapor content of air (variously measured and expressed as absolute humidity, relative humidity, cave fog, saturation debt, or dew point), evaporation rates, condensation, air movement (speed, direction, flux, etc.), barometric pressure, carbon dioxide level, radon level, and hazardous gas levels (methane, hydrogen sulfide, carbon monoxide). In addition to air parameters, cave sediment temperature, water temperature, and rock temperature are commonly monitored with cave meteorology.

Cave climate conditions are sensitive to and dependent on external climate conditions. Monitoring cave climate, especially in caves that are rarely visited, can provide insight on natural regional climate change, and in many cases, cave meteorological readings are best interpreted with surface meteorological readings from the same area. In general, the variability of temperature, humidity, evaporation, condensation, and carbon dioxide levels is greatest close to cave entrances. Deep in the cave, these parameters may vary only slightly – air temperature only tenths of a degree or relative humidity only fractions of a percent. Additionally, sediment, water, and rock temperatures tend to be much less variable than air temperatures in the same area. Near entrances, significant airflow may be expected; however, in constricted areas deep in the cave, airflow can also be highly variable.

Cave meteorological parameters are among the most commonly monitored parameters in Oregon Caves and cave management in general for several basic reasons. First, many cave processes are sensitive to changes in cave meteorology. Microclimate can influence the form and morphology of speleothems, including mineralogy and crystal structure (Hill and Forti, 1997). Decreases in humidity can cause cave-adapted animal populations to decline. An increase in cave temperature can turn an ideal bat hibernaculum into a cave unused by bats. Increases in the concentration of carbon dioxide in cave air can lead to dissolution of cave formations. Paleontological, archaeological, and cultural resources in a cave can be damaged by changes in the cave microclimate. Monitoring can assess risk to significant resources that could be impacted by natural or artificially-induced climate changes. Second, cave meteorology is relatively sensitive to human activities in caves. Particles introduced into a cave's atmosphere can act as condensation nuclei in a naturally low nuclei environment. The presence of people in a cave can significantly alter the microclimate of some low energy flow caves, and large-scale tourist activities, such as occur in Oregon Caves, will alter the microclimate even in caves with high energy flow. Third, some cave meteorological parameters, such as temperature and evaporation, are among the most readily monitored cave parameters, at least at a very basic level. Much basic monitoring can be conducted by relatively inexperienced staff, such as volunteers, Student Conservation Association (SCA) interns, and Youth Conservation Corps (YCC) workers, who can be trained to use hand-held instruments like thermometers, sling psychrometers, anemometers, or gas meters.

From a cave management perspective, monitoring of cave meteorological parameters should occur when there are significant resources that could be impacted by changes in cave climate, when management actions might affect a change in cave climate, or when control data are needed from a cave not undergoing a management action to compare to a cave that is undergoing a management action. The timing between measurements should vary depending on the type of issues that might be examined. For deep cave measurements in caves that are not being subject to management actions that might alter cave climate, seasonal measurements may provide adequate data. If caves are subject to management actions that might alter climate, or if they serve as controls, more frequent measurement, such as monthly or weekly, might be appropriate.

Monitoring of cave meteorology varies from inexpensive and moderately easy to very expensive and complex in both time and funding. Often the main cost factor is the instruments used to measure and record the data. More expensive instruments are often capable of greater accuracy and precision, storage capacity, and flexibility in timing of measurements. Cigna (2002) provides good information on a range of monitoring solutions for cave meteorology.

Evaporation can be easily measured with simple evaporation pans with standardized amounts of water. The pans must be positioned so as to maintain unobstructed airflow and avoid interference with animals such as woodrats.

Airborne moisture (humidity) and airflow (wind speed and direction) can be very difficult to measure precisely and accurately in cave conditions. Because of this, these two parameters require specialized approaches.

Humidity is difficult to measure at very high levels, i.e. at relative humidity levels above 95%, which occurs at many caves. Few specialized and often expensive instruments that can accurately measure humidity are able to function under the rigorous conditions of a cave, and many of these instruments require significant experience to obtain and interpret the results. For example, laser absorption, which measures the amount of loss of specific wavelengths as they pass through the air, very accurately measures absolute humidity, but the expensive instrument ($5,000-10,000) does not usually do well in wet environments like Oregon Caves. Less expensive instruments like sling psychrometers and inexpensive electronic sensors are used to collect general information on humidity changes, but they do not provide really accurate monitoring. The best solution may be weather-resistant, in-cave monitors, like HOBO dataloggers, that can be easily calibrated and are weather resistant and then purchase another unit of sufficient accuracy at the appropriate rate of calibration (every week, every month, etc.) to yield the minimum accuracy that one needs.

Unlike humidity, airflow is not inherently difficult to measure in cave conditions. Practical problems provide more difficulty. Although some caves have very strong air currents, many have either much more gentle airflow or experience much more gentle airflow at times. In addition, depending on passage geometry and meteorological conditions, airflow may vary significantly in different parts of a passage cross-section. In fact, airflow at the top of a passage may be in a different direction than that near the floor, especially if a cave has only one large entrance, although this has been shown to occur even at Oregon Caves. It is important to understand airflow variability in a cross-section before choosing a place to monitor airflow. Furthermore, the potential for a condensing environment causes measurement problems. Anemometers based on physical movements, like cup or propeller anemometers, sensitive enough to measure small airflows are subject to errors when condensation occurs on the mechanism. For this reason, hotwire and ultrasonic anemometers are more appropriate for cave airflow studies and monitoring. Simple hotwire anemometers provide data on flow velocity, but not direction. However, they can be used in pairs with one anemometer shielded to provide information on airflow direction as well (Cigna, 2004). Ultrasonic anemometers are beginning to be used to study and monitor cave airflow (Pflitsch and Piasecki, 2003). They have much promise for improving our ability to monitor cave airflow; however, they have some potential drawbacks. It is possible that ultrasonic anemometers could interfere with or disturb bats at Oregon Caves. Therefore anemometers that use frequencies higher than those used by area bats are recommended for Oregon Caves.

The recommended technique for monitoring cave carbon dioxide levels and the one used at Oregon Caves is non-dispersive infrared spectroscopy (NDIR) (James, 2004). Buecher (1999) discusses a variety of microclimate characterization and monitoring approaches that were used in pre-development studies at Kartchner Caverns State Park in Arizona.

Radon concentration in cave air is an important parameter that is monitored in a number of caves (including many NPS toured caves). Radon variation has the potential to be used to examine cave airflow patterns (i.e., Pflitsch and Piasecki, 2003). However, most, if not all, radon monitoring is driven by regulatory requirements aimed at safeguarding human health. The NPS Air Resources Division is currently revising radon monitoring procedures for NPS caves (Bob Carson, Mammoth Cave National Park, personal communication, 2005).

Mammoth Cave National Park is developing protocols for monitoring some aspects of cave meteorology, particularly air temperature, humidity, and airflow (Johnathan Jernigan, Mammoth Cave National Park, personal communication, 2005). When these protocols are finished, they will provide very useful guidance for monitoring these parameters. The protocols being developed focus on mixed use of hand-held instrumentation and datalogging sensors, and thus would be medium level in cost, technology, and expertise.

Automated data collection with either combined sensors and dataloggers, such as the HOBO family of dataloggers, or specialized sensors attached to dataloggers represent a medium level of complexity and expense. Dataloggers tend to be more expensive than hand-held instruments, although some temperature data loggers that can be readily used in caves are available for about $100. Acquiring cave meteorological data using dataloggers have several advantages over human recording using hand-held instruments. In general, it is more practical to take data more frequently with a datalogger. In addition, measurement errors may be reduced. Dataloggers are by and large easy to use and can be maintained and downloaded by inexperienced staff. However, the eventual storage and long-term curation of large quantities of data usually requires staff with some data management experience.

The use of dataloggers in caves is not as straight-forward as it is in many surface applications. The high humidity and frequently condensing environment in caves leads to failure in many electronic devices over time. Finding dataloggers that will work in caves for long-term application can be difficult. Only instruments rated for outdoor settings should be considered in any but the driest cave environments. In case of separate probes feeding data to a stand-alone datalogger, it may be possible to place the logger in a case with drying agents that protect the logger from cave conditions.

More expensive cave meteorology monitoring programs will use increasingly complex and specialized sensors attached to networks of dataloggers. These sensors might include very sensitive thermometers, complex psychrometers, ultrasonic anemometers, and gas chromatographs (for analyzing cave atmospheric composition). These systems will require very specialized knowledge to develop, to maintain, and to analyze the resulting data.

VITAL SIGN: AIRBORNE SEDIMENTATION

The sedimentation of dust and lint in caves is a significant issue for cave protection, especially in show caves. Natural sedimentation of dust can occur in caves due to natural cave processes such as airflow. However, when people visit caves, the natural level of dust can be supplemented by additional dust (mineral component) and lint (anthropogenic component including hair, skin cells, and clothing derived fibers). Although there likely is little dust deposition in Oregon Caves, some may occur from tiny water droplets kicked up by foot traffic and redeposited on cave features. Monitoring dust and lint in caves that have sizeable visitation or sensitive resources is important because increased deposition can have major effects on caves and management actions can increase or reduce such deposition. Dust deposition can alter and dull the color of cave formations. Dust and lint can also impact cave life. The deposition of organic materials like lint can increase food levels in the cave; the increases in food can allow the cave to be invaded by less cave-adapted species that may displace cave-adapted taxa. In addition, decomposition of organic lint on formations can lead to corrosion of the formation surfaces. Jablonsky and others (1995) and Michie (2001, 2003) provide good summaries of the issues involved with dust and lint in caves.

Dust and lint can be monitored either by examining either the material deposited or the material in the air. In both cases, monitoring both the amount and composition of the dust is most desirable. In almost all cases, comprehensive monitoring of dust will require both specialized training and specialized equipment.

Collecting dust and lint to measure deposition rates is generally straight-forward. A series of glass plates (or Petri dishes) are placed in the cave to collect falling dust. They can be placed in transects to look at trend in dust deposition or as single plates to look at spot deposition. Plates are left in the cave for set amounts of time. The amount of time that plates should be set out depends on deposition rate, the goal of the study (general monitoring or testing a particular management strategy), and sensitivity of the method of quantifying dust deposition. The plates are then removed from the cave and the amount and types of dust and lint are determined. Methods to measure the amount and/or types of deposited materials include light transmission through plates (Michie, 2001), microscopic counting and identification (Jablonsky et al., 1995), or removal for chemical or physical analysis, such as weighing or chromatography. The use of plates does not require specialized training or equipment, but analysis requires both. In general, these methods would require medium level technology and specialization. Plate collection techniques provide integrated information on dust and lint deposition over a known time period. The plates must be positioned in such a way so they are not disturbed by woodrats.

Measuring airborne dust and lint in caves can be accomplished by one of two methods. In one method, air can be drawn through a filter and the material trapped on the filter can be analyzed. Methods of analysis include microscopic counting and identification and collection for weighing and chemical analysis. Another method uses optical means, such as lasers, to measure the dispersion of light caused by airborne dust. Some types of laser measurement devices, such as aerodynamic particle sizers, can determine both the number and size distribution of airborne particles (Michie, 2004). As with the plate collection methods, airborne particle characterization requires both medium level technology and specialists to accomplish. Unlike plate collection techniques, airborne sampling provides information on the amount of dust in the air at a specific time.

If lint clean-up occurs at a cave, it would be desirable to quantify and characterize the lint that is collected in the clean-up. This can vary from simply weighing the lint that is collected to using microscopes and high-tech chemical means to characterize the lint content. When using these approaches, it is important to standardize for different amounts of collecting effort. Unfortunately, Oregon Caves tends to be so wet most of the year that much of the organic lint decomposes before it can be collected. Therefore, future studies at Oregon Caves will have to factor in the proportion of organic (mostly wool and cotton fibers) versus synthetic fibers.

VITAL SIGN: DIRECT VISITOR IMPACTS

Direct impacts of cavers and tourists on cave resources are one of the most important manageable sources of loss and destruction of these cave resources. Direct impacts include breakage of cave formations, development and expansion of trails in caves, damage to cave surfaces from traffic, and graffiti. Impacts such as these result in direct loss and damage to cave resources, including geological, biological and cultural resources. For this reason, monitoring these impacts is important. Monitoring can allow managers to understand patterns of impact, devise strategies to limit impact, and determine whether and how management actions change impacts. Related to monitoring of visitor impacts is monitoring visitor traffic in caves. Another direct impact that can occur in caves with fixed lighting is the growth of “lamp flora.”

Unlike some other types of cave monitoring, most regularly used visitor impact monitoring methods require only minimal technology. However, some require specially trained people to accurately assess impact.

Visitor numbers – Monitoring the number of visitors to caves seems like a simple task, and indeed it can be. In show caves, recording the number of people on tours can provide this basic information. In wild caves, monitoring the number of visitors can be more difficult. Registers provide one manner to estimate the number of visitors in wild caves. Cave registers are in-cave forms on which cave visitors log information such as name, age, hometown, affiliations, and caving party size. Visitors voluntarily fill them out, so they do not necessarily provide complete, accurate information. Placing multiple registers in different areas of a cave can provide some data on relative visitation in different areas. This will be done for all ungated caves at Oregon Caves. Caving permit systems, which require cavers to obtain permits to visit caves, provide an additional estimate of cave visitation. Estimates will be more accurate for caves where access is restricted by a gate or other barrier, because gates should limit the number of non-permitted entries that will take place. These monitoring strategies are all very easy to implement with SCA interns; they are all also very inexpensive in terms of needed materials.

Another approach to monitoring visitation in non-tour caves is to use some type of datalogger or automatic counter to count groups and individuals visiting caves. Several groups have developed techniques that can be used to monitor visitation. Most of these techniques have focused on using the presence of light in normally dark areas of the cave to detect and log visits (Drummond, 1992; Gibson, 1994; Johnson et al., 2002; and Toomey et al., 1999). Some have used dataloggers that record counts when an infrared beam is broken. Other types of trail counters including pressure pads and air-tube counters have the potential to be used for monitoring cave visitation, but reports do not suggest that these have been used frequently in caves. Unfortunately, calibration of all of these types of counters has proven difficult. Additionally, they provide a count of events rather than individual visitors. At this point they are better suited to provide information on timing of cave use and general patterns of visitation than they are to provide accurate visitation numbers. Overall, this approach to monitoring visitation is relatively easy to accomplish, even with inexperienced staff and relatively small amounts of money.

Direct Impacts – Several techniques can be used to monitor direct visitor impacts, such as cave formation breakage, trail development, trail compaction, etc. Five techniques discussed here are photomonitoring, formation breakage counts, visitor impact mapping, trail compaction monitoring, and LIDAR scanning.

Photomonitoring is a very important technique for a range of condition monitoring in caves and in other environments. Werker and Hildreth-Werker (1996) provided useful suggestions for improving photomonitoring of the cave environment and helped design the present system at Oregon Caves.

Formation breakage counts are a very simple means to monitor breakage of cave formations. In this technique, an inventory is made of broken formations in a cave (or area of a cave). All broken formations identified in the inventory are inconspicuously marked. In a study in

Carlsbad Caverns (Dale Pate, personal communication, 2005), small red ink dots were placed on each broken formation as it was inventoried. Broken formations are re-inventoried at intervals, and broken formations without marks are counted as new breakage. This technique is a very low-tech way of monitoring formation breakage in both tourist and wild caves. In addition, the technique does not require highly trained people to accomplish. Using indelible ink that can only be seen in ultraviolet light works best for single broken speleothems, like most dripstone. The formations can be marked facing the center of a trail, and the marks can be larger than with visible ink, enhancing the survey's efficiency. The marks are not visible to visitors.

This type of monitoring cannot be done very efficiently with speleothems such as coralloid or small visible crystals, so breakage assessment must be a semi-quantitative measure, like the sum of square foot coverage or degree of impact. As long as one is consistent with protocols, one can compare caves in a single park over space and time, though servicewide protocols on this one would be desirable.

Visitor impact mapping is another technique to monitor human impacts on caves and cave resources. Bodenhamer (1996) developed this technique as a way to quantify and monitor impacts such as formation breakage and floor surface impacts. In visitor impact mapping, a cave or cave area is examined for visitor impacts like compaction, trails, sediment disturbance, mud transferred to clean surfaces, broken floor crusts, and broken formations, and these impacts are mapped onto a detailed map of the cave. The technique, a specialized form of cave mapping, does not require specialized technology. However, it does require skill in cave mapping and training in the technique. Allison (2004) describes the application of this technique in Lechuguilla Cave, Carlsbad Caverns National Park. However, visitor impact mapping is more useful for fairly pristine, wild caves rather than caves that have been in service for quite some time, which probably explains why Oregon Caves has had limited success with Bodenhamer's methodology. The original concept of visitor impact mapping was for caves that are relatively pristine to begin with, thereby making changes more discernable, and was also more descriptive than quantitative. Combining parts of Bunting & Balks (2001) visitor impact mapping design with Bodenhamer's method is probably better in part because it is more comprehensive and so can be better adapted to paved trails that have been heavily impacted in the past. Oregon Caves is still modifying or adding to some of their methods by revising or adding more quantitative measures such as broken speleothem counts, total dissolved ionic solids/ Ph in pools, and compaction studies.

When sediment floors of a cave are traversed, trail compaction almost invariably occurs. That compaction can be a significant impact on the cave sediments. It can also impact other cave resources, such as archaeological or paleontological materials contained in the sediment fill. Compacted sediments may also inhibit the movement of some cave animals and may retard or prevent the growth of some types of cave minerals that grow out of the sediments. Sediment compaction can be easily measured by trained SCAs using fairly inexpensive equipment. A soil compaction tester or penetrometer can be used to map the soil compaction in trails and in adjacent non-trail areas. Monitoring trail compaction can be used to limit human visitation and may be used to limit access to impacted areas. In some types of sediments, bioturbation and mineral growth can reverse compaction if further compacting travel is halted or reduced. However, this does not seem to be the condition at Oregon Caves.

In very sensitive areas with unique, rare, or valuable resources, LIDAR or time-of-flight laser scanning can be used to monitor changes in the area. This is a technique that requires very expensive technology and highly specialized personnel. In this application, a laser scanner is used to map a cave area in great detail. A laser is scanned across the area, and the distance to each point in the room is measured to a high degree of precision and accuracy (depending on the set-up precisions near one millimeter are possible). These distances are used to develop a "point cloud" that maps the room in three-dimensions. Repeated scanning at intervals can be used to monitor even small changes in cave resources. This technique, although undoubtedly powerful, currently has a number of limitations in addition to cost and personnel needs when it is applied to caves. The scanning units are relatively large, heavy, and delicate. In addition, they require either large batteries or electrical connections.

Near fixed lighting in Oregon Caves, algae, cyanobacteria, and higher plants grow on moist substrates. This invasive plant growth, known as "lamp flora" can significantly impact cave geological, biological, and cultural resources. Aley (2004) provides a good introduction to the subject. In caves where lamp flora occurs, it is important to monitor both the growth of lamp flora and the actions taken to control it. Monitoring growth of lamp flora is relatively simple. Such monitoring may include photomonitoring areas of growth or manually recording site of growth. Monitoring changes in what taxa make up lamp flora growth is much more involved and expensive, but has been done at Oregon Caves (see species list).

It may be possible to quantitatively monitor darkening of formations and bedrock surfaces in Oregon Caves. A prior history of extensive touching/brushing (narrow trails), dissolved-asphalt aerosols, smoke damage, human-caused organic deposition, and our room-by-room inventory show that areas near the paved trail are darker than those further away. Although one can readily measure overall brightness from digital photos, the problem of curved surfaces is confounding, meaning that it introduces a variable that is difficult to control. A stratified random sampling protocol in which the nearest flat surface of a sufficient size is chosen from each randomly selected point might work. However, a large number of flat surfaces would have to be photographed with two slave flash units at 45 degrees angles toward the surface on each side of the camera in order to create a statistically valid study, so that fixed monitoring points like those used in the Werker's photomonitoring system would be too costly. Other considerations might include use red light, as it causes darkened spots on formations to contrast more prominently with unstained areas, or the use of a photospectrometer, an instrument used in photography that can measure darkness. Intensive efforts to set up photographs at randomly sampled points may not be justified, as any mitigation to reduce darkening is largely cosmetic, except where staining is organic.

VITAL SIGN: SEASONAL ICE

Oregon Caves has seasonal ice at its entrances. This ice is important for several reasons. First, it helps control the cave microclimate. Second, the extent of ice in caves can itself be used to interpret climate changes (Luetscher, et al., 2005). Yonge (2004) discusses the characteristics of ice in caves and different mechanisms that lead to seasonal and permanent ice in caves. Natural variation in climate (in particular, local and regional variations in precipitation and temperature) can affect the extent of ice in caves with such ice. In addition, management actions may also affect ice extent (thickness, area, or temporal). For instance, putting in an air restrictor door at Oregon Caves reduced ice damage in the cave in areas where, based on the sharpness of the exfoliated layers, ice was not present in the last few thousand years or so. Monitoring ice extant may provide information on both long-terms changes in climate and effects of management actions.

Ice extent and thickness in caves can generally be monitored using inexpensive means that do not require specialized personnel. The extent of ice can be readily mapped using several techniques. Mapping with respect to set landmarks can be accomplished using a detailed map of the cave area, simple survey instruments, a prepared set of landmarks, or an established grid. Repeat photography is another method for monitoring ice extent, although with very clear ice, it may be difficult to discern ice extent in photographs. Historical photographs may be used to estimate past ice volumes and extend the monitoring record (Luetscher, et al., 2005). The best time to accurately map ice thickness and derive useful information from such an effort is to survey the combined total during cave bat surveys. Measurements taken several times per winter season during bat counts will produce an averaged yearly effect that smoothes out seasonal changes, which is preferred to synoptic measurements taken annually on the same of the year, which would be confounded by variation in a particular season.

VITAL SIGN: CAVE DRIP AND POOL WATER

Dripping and pooled water are important components of many cave environments. Dripping water transports minerals, microbes, and chemicals into the cave. It is responsible for depositing the minerals that result in the growth of many types of cave formations, most notably stalactites and stalagmites, but other types as well (Hill and Forti, 1997). Pooled water formed by infiltration (through dripping or flowing) is also responsible for the formation of several types of cave features, including shelfstone, rafts, pool fingers, and pool spar (Hill and Forti, 1997). Dripping and pooled water can act to maintain cave moisture. Drip water can also transport contaminants into caves, although so far this does not seem to occur at Oregon Caves.

Because of its crucial roles in depositing cave formations and maintaining moisture, monitoring cave drip and pool waters is desirable. Three major parameters that are basic to monitoring drip water are drip locations, drip rate, and drip volume. In addition to these basic parameters, drip water chemistry, microbiology, and temperature can be monitored in more complete programs. For pool waters, the basic parameter for monitoring is often water level. In more complete monitoring programs, pool water chemistry, microbiology, and temperature would potentially be monitored.

Changes in the amount or distribution of dripping or pooling water in a cave may be the result of natural processes, like drought, or modifications caused by human action, which may include changes in land use in the contributing watershed for the cave, changes in cave microclimate caused by management actions, etc. Monitoring may be used to identify such changes and to plan mitigation, if appropriate.

Monitoring water quality (chemistry, microbiology, etc.) can provide important information on contaminants that may be brought into the cave through infiltrating water and damage cave resources. Caldwell (1991) examined pools in Carlsbad Caverns to determine the impacts of visitors on the chemistry and microbiology.

As with cave meteorology, there are two basic approaches to monitoring drip and pool water parameters. The lower cost and technology approach is to manually monitor parameters with hand held instruments. Using automated sensors tied to dataloggers is the higher-end approach. Monitoring the location and amount of dripping water in a cave is often accomplished manually. Several different methods can be used, depending on the type of monitoring, available resources, and accessibility of sites. Buecher (1999) and Sanz and Lopez (2000) discuss several manual drip monitoring methods. One approach is to monitor drip rate, drip volume and potentially other parameters such as water chemistry at defined drip monitoring locations. Drip rate can be estimated using a stop watch by either counting the number of drips in a set time or determining the time for a set number of drips. The estimate will improve as the observation time increases. Drip volume can be estimated by using a graduated cylinder to collect dripping water. Again, estimates can be made by either determining the volume in a particular time or the time to fill to a particular volume. Water collected in such a study can be used to monitor drip water chemistry (Buecher, 1999; Musgrove and Banner, 2004). Another approach to monitoring the quantity of dripping water in a cave or cave area is to monitor water accumulation in random areas rather than choosing specific drips. Buecher (1999) did this by placing circular 23-cm diameter pans in locations and measuring water accumulations over set times. Drip rates have been measured in most rooms of the cave. This should be done again as the averaging will reduce individual variation such that the averaged drip rates likely is most reflective of overall precipitation patterns from year to year.

The problem with measuring individual drip rates or speleothem deposition (speleogen formation and destruction is just as important but harder to measure) is that there is so much individual variation that has nothing to do with human impacts. This is why Oregon Caves uses large plastic containers attached to drip buckets. Even this is likely to be not as good as draping plastic over much larger areas, although this latter experiment is likely to impact both biologic and geologic processes in Oregon Caves. This may not be necessary for Oregon Caves as we are putting in an automatic stream flow gauge because we have only one major water outlet and therefore can measure the sum of infiltration and evaporation rates, once again smoothing out individual variation. However, most park caves that we want to monitor don’t have this luxury. Similarly, LIDAR can at most only measure the deposition of a few fast-growing speleothems while putting out a large number of calcite blocks under different types of dripping or flowing water will smooth out variation.

Specific conductivity is probably the most commonly measured chemical parameter in drip water monitoring. It is a preferred parameter because it is relatively easy to measure using inexpensive hand-held instruments and because it provides important information on the potential for water to deposit or dissolve cave minerals.

Another very commonly measured water chemistry parameter in dripping, pooling, and flowing water is hydrogen ion activity (expressed as pH). The pH value of karst water is important in its own right and in calculating other values that provide important information about karst systems, such as saturation indices. Measuring pH can be problematic under field conditions, especially when small variations in pH can lead to large differences in calculated parameters. Sasowsky and Dalton (2005) provide a good discussion of the problems associated with field measurement of pH and provide recommendations for improving measurements.

Automated drip water monitoring is significantly more complex and less common (Genty and Deflandre, 1998). There are no standard, off-the-shelf solutions to monitoring drip frequency, drip volume, or drip chemistry. A variety of custom-built instruments have been installed for scientific research, as opposed to routine monitoring. Some of these instruments use a tipping bucket approach to measuring frequency and volume of drips (Beddows et al., 2005), as is the case in Oregon Caves. Less often, exotic approaches like counting using laser beams, photoelectric, or a vibrating drum principle (Baker and Brunsdon, 2003; Genty and Deflandre, 1998) are used to measure drip frequency.

Monitoring of pool water levels can be an important component of a monitoring program. Changes in pool level may indicate changes in cave climate; for example, changes in pool level at Carlsbad Caverns were an important indicator of increased evaporation due to elevators (McLean, 1971, 1976). Monitoring pool water level can be accomplished manually by either measuring pool depth at a set point or measuring distance to the pool surface from a set point. The most common means of automating measurement of pool levels is through the use of pressure transducers attached to dataloggers. Such a transducer could be put into a pool above the Imagination Room and attached to the Imagination Room data logger. Another one could be put into a pool near the bottom of the Spiral Stairs and attached to the datalogger there.

The monitoring of pool chemistry depends on the parameters being measured. U.S. Geological Survey (variously dated) provides guidance on measuring water quality parameters. Krawczyk (1998) also describes procedures of measuring a variety of chemical parameters including pH, dissolved oxygen, specific conductivity, hardness, calcium, magnesium, sodium, potassium, bicarbonate, chlorides, sulfates, nitrates, phosphates, and silica. As with pool level, some of the water quality parameters can be monitored continuously or periodically with datalogged sensors. The ease and utility of this approach varies with parameters. For example, it is difficult to automate pH sensors for long term monitoring because accuracy, measurement drift, and calibration issues are significant in these sensors. Consequently, this is not done at Oregon Caves.

Microbiology can be an important parameter to monitor in infiltration water either in drips or pools. The most common reason for monitoring microbiology in cave drips and pools is to detect deleterious bacteria entering the cave due to contamination from human or animal waste. The presence of elevated coliform, fecal coliform, and E. coli are common indicators of potential contamination. These parameters are measured using standard procedures for other freshwater, including wastewater and drinking water; Myers and Wilde (2003) provide guidance on standard accepted procedures for biological indicators of water quality.

VITAL SIGN: MICROBIOLOGY

The study of the microbiology of caves is a relatively recent development and is evolving rapidly in terms of both methodologies and results. Recent studies have shown that microbes play an important role in a number of cave geological processes including wall corrosion and development of corrosion residues, precipitation of a variety of secondary minerals and speleothems, and sulfuric acid speleogenesis and cave enlargement (Barton and Luizer, 2005; Barton et al., 2001; Northup and Lavoie, 2001). The microbiology of caves can potentially be significantly altered by a large range of activities such as exploration, land use changes, construction above caves, etc. that lead to contamination of infiltrating water, and tour activities (Hunter et al., 2004; Ikner, 2004). The potentially profound role that microbes play in cave processes and their susceptibility to alteration due to human activities makes cave microbiology a potentially important vital sign to monitor.

Most of the studies that have been undertaken so far are exploratory in nature. They focus on what microbes are in the system, how different cave microbial ecosystems function, or how microbes are involved in different cave processes. For this reason, there are no standard methods that have been agreed upon for studying cave microbiological systems, let alone methods for standardized monitoring. Some parameters that are likely to be important in monitoring include microbe diversity, activity of various microbial ecosystem components, and presence of microbial taxa indicating disturbance or perturbation of natural systems. Any microbiological monitoring beyond simply identifying the presence of certain common bacteria associated with human activity (e.g. total coliform, fecal coliform and E. coli) will require working with specialists.

Cave microbiology might be left out of geological monitoring until we know whether or not rock alteration is still active at Oregon Caves. Work by the Palmers on the age of the resulting calcified floor deposits suggests that at least in Carlsbad rock alteration is mostly inactive now. However, other studies suggest that the bacteria are still active in Lechuguilla and Spider Caves, other caves in Carlsbad National Park. Nobody yet knows if changes in cave wallrock microbiology can be a proxy for changes in geology caused by human impacts.

Understanding human impacts on cave sediments and soil bacteria and root density is probably more important than investigations of wall rock alteration as bacteria in those sediments are more likely sensitive to changes in atmospheric carbon dioxide and soil temperatures. They are among the main determinants of soil properties and are the major factors in how much carbonic acid reaches caves. In at least two soil and vegetation types the contribution to carbonic acid is roughly equal between root respiration and microbial processes. Consequently, the biggest microbial impact on Oregon Caves is likely to be from changes in soil fungi, bacteria, and probably Archaea or an increased spread in human E.-coli and Streptococcus. Back in the early 1990s, a microbiologist at Oregon Caves did a biological oxygen demand survey of pools near the trail and she found that natural processes in Oregon Caves' seasonally very wet and then dry system overwhelmed any detectable changes from lint, lampenflora, etc. despite distinct differences in total dissolved solids and pH. However, TDS should be measured in determining visitor impact, in part because it is inexpensive and likely is a measurement of changes in water quality from both atmospheric deposition and waterflow from more impacted trail areas.

Elevated atmospheric carbon dioxide concentrations generally increase the carbon to nitrogen ratio of plant tissue. This, along with fire suppression, can lead to the accumulation of hard-to-break-down biomass in which nitrogen is sequestered (locked up). A Pacific Northwest study suggests that on relatively nitrogen rich sites like our area, carbon sequestration may increase about 25% over a 100 year period of elevated carbon dioxide and temperatures (McKane et al. 1997). In response to increasing nitrogen scarcity, conifers and other plants that use less nitrogen and whose roots breath out carbon dioxide less intensely likely would become more common and hardwoods that use more nitrogen and respire more from their roots would become less common. This would decrease the fungal and bacterial decomposability of litter (decreasing their release of carbon dioxide), thereby further reducing the cycling of nitrogen and leading to progressive nitrogen limitation. The result, somewhat counter-intuitively, is that soil carbonic acid may actually decrease from elevated atmospheric carbon dioxide, in part because of reduction in both microbial and root respiration and less nitrogen available for biologic activity. Measuring the carbon dioxide content of air after it equilibrates inside a concave disk over both cave sediments and surface soils could be joined to the measurement of biological oxygen demand (BOD) of these sediments. Major changes in these parameters could signal a change in the amount of carbon acid and/or organics entering caves which are among the major drivers of geological and biological processes, respectively, in Oregon Caves.

VITAL SIGN: STABILITY – BREAKDOWN, ROCKFALL, AND PARTINGS

The stability of the cave ceiling in terms of number, location, size, and frequency of rock falls can be an important vital sign to monitor. Breakdown in caves is a natural process that occurs for numerous reasons (White, 2004). The location, style, and cause of breakdown vary spatially within the cave and temporally in the speleogenesis of the cave. Monitoring of breakdown is generally undertaken for two somewhat different reasons. One purpose of monitoring can be to understand the process on-going breakdown process in order to monitor changes more effectively to determine if some sort of mitigation is needed in terms of safety, i.e. determining if and when to limit people traveling under a particular area suspect of being prone to breakdown.

Monitoring breakdown to understand changes in the process due to changing cave conditions can be undertaken in several ways and at several time frames. However, monitoring for safety should be undertaken in ways that provide some ability to predict the likelihood of additional breakdown. In addition, monitoring to understand the pattern of breakdown can be done on whatever time frame is convenient; in other words, monitoring can take place annually, or on even longer time frames. Monitoring for human safety, on the other hand, should be done on time frames that are meaningful for protecting people from possible dangers. The more frequent the interval of monitoring, the better equipped one will be to warn people of potential dangers. The logical extension of this observation is that to have a true warning system for potential rock fall, real-time data gathering and analysis may be necessary.

Changes in rock fall number, location or size may indicate that changes have occurred in the cave microclimate that promote more rock falls. For example, changes in entrance configuration that lead to more penetration in freezing temperatures can lead to increased rock fall due to freeze-thaw ice wedging.

One of the simplest means to monitor breakdown is to simply record the date and location of each new piece of breakdown that occurs in a particular section of a cave. This is simple in theory, but it can be complex in practice. It may be difficult to distinguish new breakdown from existing breakdown in a cave passage with a rocky floor. In addition, if the cave is not visited very often, timing is impossible to determine, and new rock fall may be hard to identify. This technique is probably most amenable to show caves in where daily visitation occurs by people very familiar with the cave (guides); in addition, tour trails provide a clear area that can be monitored.

A simple, manual method to monitor movement on bedding plane partings and cracks that may lead to breakdown is to monitor the sizes of those cracks using mechanical means. One type of mechanical means is to place hard plastic wedges into the cracks. If the wedges loosen, it may be an indication that movement is occurring on the cracks. A similar approach is to affix small strings or bands across the cracks. Breakage of the string or band can indicate movement. As with the wedges, the bands or strings must be composed of a material that will not expand or contract significantly under cave conditions.

To accurately monitor movement on cracks and bedding planes, technology and expertise is needed. Getting the appropriate assistance from a geological or mining engineer is especially important if the goal of monitoring is to increase safety. The mining industry uses a variety of techniques to monitor the stability of rock ceilings and walls. These include wire extensometers, EDM prism surveying, micro-seismic monitoring, surveying displacements, displacement transducers, time domain reflectometry, inclinometers, and LIDAR (Girard and McHugh, 2000; Bhatt and Mark, 2000).

VITAL SIGN: MINERAL GROWTH

Secondary mineral formations, i.e. speleothems, are an important geological cave resource. The deposition and loss of these secondary minerals in caves are very important processes. These processes have the potential to be monitored. However, in most cases the processes are too slow to be monitored using simple methods. Seasonal mineral growths that may occur due to changes in cave microclimate represent an important group of exceptions to the general rule of the slow growth of cave formations. However, such minerals are not known from Oregon Caves.

Color changes and staining of cave formations may be an indicator of human impacts that may be degrading geological resources or the cave. In some cases local staining can be caused by cave visitors touching a formation. Groundwater contamination with sewage or metals may also result in changes in the color of formations in a particular area.

Monitoring the seasonal growth and loss of cave mineral deposits is usually done manually. The extent of mineral deposits can be mapped in both space and time by trained individuals. The amount of training and equipment that is required to identify and map mineral deposits depends on the particular minerals that occur seasonally. Potential seasonal mineral deposits to be monitored are generally identified through mineralogical inventories. Changes in the pattern and timing of mineral growth may indicate changes in regional climate or alterations to microclimate conditions in the cave. Because the deposition and disappearance of these minerals is seasonal, it is important to map the occurrences and extent of these minerals in different seasons.

As LIDAR and other laser scanning techniques have improved, it is becoming possible to measure growth rates on some of the faster growing speleothems. In the near future it is possible that this technology may become widespread and inexpensive enough to be used to monitor changes in speleothems growth rates. However, at this point, the technology is more appropriate for scientific studies of speleothems growth. There are no known computer programs that will compare changes between two or more LIDAR images, but this should be investigated further. There are also few human impacts you could measure most efficiently with LIDAR, at least in caves. Rock polishing and human-caused airborne deposition (asphalt droplets, lint, dust, etc.) generally don't have enough thickness change to register even on LIDAR. The situation on the surface is different.

Color changes and staining of formations can be an important indicator of impacts to cave mineral resources. Monitoring for staining and color changes on formations is probably best accomplished as part of a photomonitoring program. To be able to accurately determine color and track changes, it is important to include a color standard in your photomonitoring pictures.

VITAL SIGN: SURFACE EXPRESSIONS AND PROCESSES

Although caves are an underground feature, they are intimately tied to the surface by conduits that transport water, sediment, and organic matter both in and out. These conduits vary from large entrances and springs to microscopic crack and porosity. Karst processes closely link the surface to the caves through springs, sinkholes, cracks, etc.

Because the surface and cave are intimately related, monitoring of the surface may provide important information about the state of cave and karst resources. In addition, cave and karst resources can be degraded due to actions on the surface. For these reasons, monitoring of the surface can be an important component of cave and karst monitoring.

Land use changes may alter or degrade cave and karst resources by affecting water quantity, quality, or distribution. Monitoring land use changes is especially important for managers who have caves whose watersheds extend beyond the area they have control over, as is almost certainly the case in Oregon Caves. In cases such as these, actions of land managers many miles away may result in changes in caves that are being managed to protect resources. For example, in the well-developed karst of Missouri, dye-tracing has indicated that water from as far as 61 kilometers away (38 miles) (straight-line distance) is discharged at Big Spring (Imes and Fredrick, 2001).

Identifying changes in landscape, such as development of new sinkholes in karst, and monitoring changes in land use that may affect cave and karst resources are often best achieved using periodic remote sensing methods such as airborne and satellite imagery and data gathering.

Airborne LIDAR has been used to identify karst features in Oregon Caves. It has notably been used to map karst topography in rain forests in Alaska (Baichtel and Langendoen, 2001;

Langendoen and Baichtel, 2004). It has also been used in the low-lying karst of central Florida to both identify and map sinkholes (Seale et. al., 2004) and to predict the location of potentially hazardous subsurface features (Montane and Whitman, 2000). These studies have focused on the use of airborne LIDAR to inventory karst features rather than monitor them for changes; however, monitoring would be an additional possibility once inventory was completed in an area. Airborne LIDAR is a powerful tool for monitoring changes in karst landscapes.

Remotely sensed thermal infrared imagery can also prove useful in identifying and potentially monitoring karst features. Campbell and others (1996) successfully used airborne thermography to map springs and loosing stream reaches in northern Alabama (Campbell et al., 1996; Campbell and Keith, 2001) and Tennessee (Campbell and Singer, 2001). The use of thermography to identify or monitor non-spring cave entrances is less developed, but it is an area of active research (Thompson and Marvin, 2005). Its use at Oregon Caves is a low priority due to the small size of the marble (~20 acres) and the likelihood that all or most accessible entrances have been identified.

Springs are an important location for monitoring potential impacts on cave and karst systems. They provide a window to the water that is flowing through the karst system. Monitoring water quantity and quality can be important in monitoring the overall state of karst systems and related caves, and changes in the quantity and quality of that water may be symptomatic of changes that are degrading cave resources, such as changes to land use or contaminant leakage. As with other general water quality and quantity monitoring, such as in streams and wells, spring monitoring programs should be designed in consultation with hydrologists or hydrogeologists who specialize in karst aquifers. A water gauging station at the entrance of Oregon Caves will be installed in the summer or fall of 2006. White (2005) provides insight into spring processes and to the ways spring discharge and chemistry can be monitored.

Numerous agencies, including the National Park Service Water Resources Division, United States Geological Survey Water Resources Program, the Environmental Protection Agency Office of Water, and various state agencies, can provide additional guidance on water monitoring and access to hydrologists to assist in developing monitoring programs.

VITAL SIGN: REGIONAL GROUNDWATER LEVELS AND QUANTITY

Caves, and solutional caves in particular, are often an expression of regional groundwater flow. Changes in local or regional aquifers may affect cave resources by changing cave microclimate, flooding previously dry areas, drying existing pools or streams, or altering dissolution or deposition of minerals. Both natural processes, such as drought, and anthropogenic processes, including groundwater pumping, surface flow alteration, and chemical contamination, can alter the water quantity and quality of local and regional aquifers. Processes such as pumping or drought, which lower water levels in regional aquifers, may impact caves in the area. In addition, these processes may cause other impacts in karst terrain; one notable impact is increased sinkhole collapse.

Monitoring local or regional karst aquifer associated with a cave may be an important tool for understanding and protecting cave resources of all types. Regional groundwater can be monitored in caves (e.g., pool water and stream water) or on the surface using springs. There are two important surface springs at Oregon Caves.

Water quality measurements that are needed depend on potential threats to the regional and local aquifer and caves. Basic parameters for monitoring karst waters include temperature, pH, dissolved oxygen, specific conductivity, hardness, calcium, magnesium, sodium, potassium, bicarbonate, chlorides, sulfates, nitrates, phosphates, and silica (U.S. Geological Survey, variously dated; Krawczyk, 1998). In addition, microbiological parameters, such as coliform bacteria, fecal coliform bacteria, and E. coli may be important parameters for detecting contamination from septic systems.

VITAL SIGN: FLUVIAL PROCESSES

In many caves, particularly karst ones, water flows in underground streams and rivers. Those streams and rivers are important for many reasons. They are often the main agent of on-going speleogenesis in their caves, as is the case with Oregon Caves. They provide important habitat for numerous aquatic species, although monitoring at the Monument so far has shown very low diversity of cave waters (one water mite, one amphipod, and one caddisfly species).

The properties of these streams and rivers, including water quality, water quantity, sediment characteristics, and distribution of water inputs, are subject to alterations that may degrade cave and karst systems. Water quality can be affected by human activities and land use changes, septic systems (Oregon Caves) and non-point-source pollution. The quantity and distribution of waters can be impacted by such things as impervious cover, channelization, sinkhole modification, and storm water diversion (Oregon Caves). Changing land use patterns around sinkholes and other inputs can radically change the sediment load, balance, and characteristics of a cave stream. Changes such as these can, in turn, alter bed characteristics.

Monitoring of fluvial processes will be covered in the Monument's surface management plan. Many of the approaches described in that chapter can also be applied in cave streams. Among the most important parameters for monitoring cave streams are water quantity, turbidity, and water chemical characteristics. Changes in stream bed, in particular siltation or scouring, may also be quite important; however, these may have more effect on biological systems in caves than geological resources. In addition, various agencies, including National Park Service Water Resources Division, United States Geological Survey (USGS) Water Resources Program, and the Environmental Protection Agency Office of Water have provided additional guidance and assistance in monitoring cave stream parameters. For Oregon Caves this had included USGS and Oregon state hydrologists. In addition, references such as U.S. Geological Survey (variously dated) and Krawczyk (1998) provide details on appropriate techniques.

Developing a monitoring program for a cave, set of caves, or caves and associated karst landscapes is a complex task involving many disciplines. Although these errata have focused on vital signs that are either geological in nature or which may significantly influence geological processes and resources, a complete monitoring program would also focus on biological resources (including bats, other vertebrates, invertebrates, and microbiology), cultural resources (archaeological and historic), and paleontologic resources. In addition, monitoring programs must follow a systematic inventory, which is necessary to identify the resources to be monitored and the potential impacts to them.

Since monitoring is presumably tied to management actions and needs, it is important to identify the vital signs that are most subject to impact under existing conditions and under conditions that are anticipated. The monitoring of some vital signs is likely to be important under a wide variety of conditions. For example, most cave monitoring plans will probably include at least some monitoring of cave microclimate. The reason for this is that cave microclimate may affect a wide range of geological, biological, and cultural resources in a cave. Other types of monitoring may be limited to caves that undergo particular human-caused impacts. For example, monitoring of lamp flora growth or lint deposition is applicable only at or near the paved trail and/or lighted portions of show caves such as Oregon Caves. Water quality monitoring is likely to be more important where a significant threat of contamination exists due to land use, although it is also important in monitoring the effects of the restoration of a more natural (frequency-wise) fire cycle through prescribed burns. Since there is likely to be little impact if any on the Monument's cave or karst systems, the park's surface management plan will recommend that surface water quality at Oregon Caves be monitored for at least several years after the sewage drain field upgrade to determine if and when chloride and nitrate levels become closer to estimated pre-drain field conditions.

Budget is also a significant factor when designing a monitoring program. Fortunately, most of the basic means for monitoring geologic resources in caves do not require expensive, specialized equipment. However, they often require either trained or specialized personnel. Automating some of the measuring, where possible, may reduce the time requirement for personnel. However, the larger volumes of data that general result from this approach may require personnel with more training to adequately analyze the results.

Cave parks have a great need for a "cave equipment and protocol website" where staff can post case studies or comments to evaluate products or people or describe where to purchase specific equipment or how to contract recommended consultants. Based on this information, a national organization like the National Cave and Karst Institute could be responsible for or delegate the updating of this website which would include a list of best available technology and human contacts as well as a hierarchal-based prioritized monitoring system that could help direct resource management at caves with less funding.

Few if any caves have implemented a monitoring program that addresses the entire list of vital signs discussed in this appendix, let alone the biotic and cultural resource monitoring that would constitute a complete monitoring program. However, the above list of vital signs should serve as a guide to what might or should be monitored, depending on resources needing management, potential impacts and threats, budget, and availability of experienced assistance.

Based on comparison with other caves with known visitation rates and the professional judgment of experienced cavers, all parts of the proposed caving route had been traveled by at least a thousand people prior to a trial run in 2001. Therefore, some baseline studies can be done in the first year of caving tours because the environmental impact of the number of people on the route during that length of time almost certainly would not be measurable.

Baseline studies that have been completed or will be completed before the proposed start of caving tours include bat monitoring with Anabat II detectors, DNA studies, and radon monitoring. Impact mapping of both the proposed caving route and the main trail will utilize a modified version of mapping criteria used by Bunting & Balks (2001) and Bodenhamer (2005). A plan to measure the amount of discoloration on white speleothems and relate it to distance from the trails was dropped due to the inability to eliminate confounding factors such as the uneven shape and varying wetness of surfaces. Added to the impact survey will be a sediment porosity sampling, which will see whether a penetrometer can be used as a proxy for measuring sediment compaction. A cultural affiliation study will be completed by the end of September 2006. Except for more biologic inventories (see below), no other studies have been suggested by the various respondents as a way to complete baseline studies. It is not clear what additional research could be conducted along the proposed caving route to inventory baselines that would yield useful information other than past or ongoing studies and studies proposed in the EA and this errata to measure future impacts.

It is not possible to conduct complete biologic or other studies without further impacting the cave or jeopardizing the integrity of future studies that may be conducted with advanced and less damaging technology and techniques likely to be developed in the next few decades. Funding of any monitoring or inventory project at Oregon Caves is largely contingent on the magnitude, scope, and scale of actual or possible impairment threats to park resources and the urgency and feasibility of mitigating or preventing such threats. Therefore, any proposed study to monitor human impacts will need to be weighed for its effectiveness in answering impact questions versus the effectiveness of other studies and projects that seek to monitor what likely are more serious human impacts and/or mitigate or prevent human impacts both in the cave and on the surface of the Monument. A watershed assessment from the summer of 2006 to 2008 will address some of these concerns by relating impacts above ground to human impacts underground, such as changes in vegetation as a result of fire suppression or climate change.

The focus of our monitoring efforts should be on processes that management actions are likely to have some impact in terms of restoration, mitigation, prevention, etc. However, the effect of global warming and increasing carbon dioxide likely is already having a significant effect on cave microclimates, speleothems, and speleogens although we don’t know how severe the impact is because we haven’t done the necessary monitoring. So how can we prioritize our monitoring efforts if we don’t know what the substantial human impacts are and whether or not they might someday rise to the level of impairment?

In other words, the only way we might be able to do something to mitigate the impact of global warming and carbon dioxide increases, such as changing entrance sizes or prescribed burn plans, is to know more about our caves via inventory and monitoring. Therefore, we shouldn’t disregard monitoring a particular impact just because at present we can’t see exactly what we can or should do about the impact or because we think we know that we can’t do anything about it. Monitoring solution rates via calcite slabs nearly identical in shape and weight is rather inexpensive. There is also value in being a witness to major impacts even if we can’t directly and/or quickly reduce those impacts. Perhaps our visitors will if they get a strong enough message from the parks backed by science.

We need a formula that more comprehensively helps us decide whether to monitor something. Such a formula might be the sum of: 1. (Whether the potential or known intensity, extent or duration of an impact will likely cause impairment), 2. (Whether we might in the present or future be able to do something to reduce the human-caused impact if we had more data), and 3 (whether we are likely to get useful data that addresses 1 and/or 2) / divided by 4 (cost in time, money, and impact on resources). We do parts of this in writing PMIS statements, EMS plans, inventory and monitoring plans, and in approving or disproving collecting permits but rarely do we combine these in justifying whether or not to pursue a particular course of action. Whether or not some formula is adopted, there should be more discussion in the plan of impacts from our monitoring efforts. Sometimes the only way to get the information you want involves so many repeated trips to caves that the impacts, safety, and economic costs are not worth it.

Using an indelible ink that can only be seen in the ultraviolet will work best for single broken speleothems like most dripstone. You also can't do this monitoring very efficiently with speleothems like coralloids or small visible crystals so you have to do a semi-quantitative measure like the sum of square foot coverage and degree of impact. As long as you are consistent with your protocols you can compare caves in a single park over space and time but it would be nice to have servicewide protocols on this one as with others.

The Park has tried using Bodenhamer's methodology for over a year and it hasn't worked all that well, probably because it is mostly designed for non-paved trails in caves that are fairly pristine to begin with (thereby making changes more measurable) and may be too subjective or semi-quantitative. Combining parts of Bunting & Balks (2001) protocols with Bodenhamer's 2005 protocols is better in part because it is more comprehensive and so can be better adapted to paved trails that have been heavily impacted in the past. We are still modifying or adding to some of their methods by revising or adding more quantitative measures such as broken speleothem counts, total dissolved ionic solids/ Ph in pools, and compaction studies.

Darkening of formations and bedrock surfaces could be a good quantitative way to monitor in our case because of our prior history of extensive touching/brushing (narrow trails), dissolved-asphalt aerosols, and smoke damage and our room-by-room inventory which shows that areas near the paved trail are darker than those further away. However, although you can readily measure overall brightness from digital photos, Oregon Caves hasn't found a way around the confounding problem of curved surfaces. The resource staff may try for a stratified random sampling protocol in which the nearest flat surface of a sufficient size is chosen from each randomly selected point. The number of flat surfaces that we would have to photograph would have to be so many so as to be statistically valid and smooth out the data that the park likely could not use fixed points such as the Werker's system (2005) because it would be too costly. However, the park likely would have to photograph even more areas to be statistically valid if we don't use fixed points.

The geological monitoring system needs to be better integrated with the inventory system. However, cave microbiology might be left out of geological monitoring until we know whether or not rock alteration is still active In other words nobody knows yet if changes in cave microbiology can be a proxy for changes in geology caused by human impacts.

On the other hand, understanding human impacts on soil bacteria and root density probably is more important as these biologic features are sensitive to changes in atmospheric carbon dioxide and soil temperatures and are among the main determinants of soil properties and are the major factors in how much carbonic acid reaches caves. In at least two soil and vegetation types the contribution to carbonic acid is roughly equal between root respiration and microbial processes. Consequently, the biggest microbial impact on Oregon Caves is likely to be from changes in soil fungi, bacteria, and probably Archaea or an increased spread in human E.-coli and Streptococcus. Back in the early 1990s, a microbiologist at Oregon Caves did a biological oxygen demand survey of pools near the trail and she found that natural processes in Oregon Caves' seasonally very wet and then dry system overwhelmed any detectable changes from lint, lampenflora, etc. despite distinct differences in total dissolved solids and Ph. However, TDS should be measured in determining visitor impact mapping in part because it is inexpensive and likely is a measurement of changes in water quality from both atmospheric deposition and water flow from more impacted trail areas.

Often long-term monitoring involves using a less expensive proxy for measuring change in monitoring after the baseline. For example, the park has had extensive work in delineating the types of water (bedding plane, vertical cracks, stream, pool) in Oregon Caves through the use of flow rates and ionic concentrations. Plotting pH versus total dissolve solids (TDS) by season for most of these types of water showed distinct populations that you could draw a circle around. Thereafter you can do an inexpensive monitoring using just pH and TDS and then, if a monitoring sample plots far outside the circle, you might want to do a more expensive analysis to see, for example, which ion (if any) is unusually high or low and whether that suggests human impacts.

Similarly, the park have had inconsistent results from a penetrometer over the last year between samples that have been greatly compacted versus areas not compacted by humans. This may be because we likely are largely measuring a resistant to compaction that is confounded and complicated by both grain size and past compaction history. So an effort will be made take sediment samples out of the cave without changing their porosity and then kilning the samples, weighing them to get a rough porosity, and doing a grain size analysis. If good correlations are found than the park might be able to use the penetrometer in the future to measure change with minimal expense.

The problem with measuring individual drip rates or speleothem deposition (speleogen formation and destruction is just as important but harder to measure) is that there is so much individual variation that has nothing to do with human impacts. This is why the park uses large plastic containers attached to drip buckets. One park hydrologist suggested draping plastic over much larger areas. This may not be necessary for Oregon Caves as the park is putting in an automatic stream flow gauge because we have only one major water outlet and therefore can measure the sum of infiltration and evaporation rates, once again smoothing out individual variation. However, most park caves that we want to monitor don't have this luxury. Similarly, Lidar can at most only measure the deposition of a few fast-growing speleothems while putting out a large number of calcite blocks under different types of dripping or flowing water will smooth out variation.

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