Generic Cave Inventory Plan

By John Roth, 1998

Where to Start: A comprehensive literature review and compilation of existing data into usable and lasting forms is a prerequisite to designing a park-specific monitoring program. Park staffs cannot inventory and monitor everything. This is especially true for caves as most have very incomplete data bases and working inside them is very labor-intensive and hard on equipment. Therefore an I&M program must be designed to address critical resource management issues and concerns, those that involve significant human-caused impacts both ongoing and potential.

Cave ecosystems, especially low energy ones, tend to have both low resistance to human-caused impacts and low resilience (bounceback to original conditions). The same conditions that preserve a wide range of resources from surface erosion, etc. will also preserve human impacts for a long time. Regeneration after impact either doesn't occur or usually occurs very slowly. These general considerations should guide cave management, including research, prevention, mitigation, and restoration.

GIS: Standardized and accurate surveys and inventories are crucial for establishing baselines, directing future monitoring, and preventing or mitigating human-caused changes. All cave inventories, monitoring, sampling should be tied by azimuth, inclination, and distance to the nearest semi-permanent survey station/marker. Most surveys should be combined with on-site inventories.

Protection: Data collection sites should be secured as best as possible from disturbance, especially from humans and small mammals. Placement of equipment, inventory markers, and the handling of fossils and historic or prehistoric artifacts and fossils should be done with latex gloves to reduce salt, skin oils and other inadvertent biological attractants, deteriorants, or contaminants that could compromise location, curation, dye tracing, microbial cultures, dating, etc. In some cases, filter masks may have to be used as well.

Consistency: Duplicate sampling should be at least 5%. This includes sending different parts of the same sample to different labs, sending duplicate samples to the same lab, and inventorying the same area using different teams one after another. Inventory items for which there is too great a range of duplicated data should be either thrown out or revised.

Data Storage: Data can be entered on site into a data logger, except where physical conditions or the breath of the survey warrant temporary storage on written survey and inventory forms and/or notebooks that are water resistant, such as "Rite in the Rain" paper. Hard copies should be produced within one week of data collection and kept in a building not adjacent to where primary data is curated. See Wilen and Rodiek (1980) for details on data collection and information management.

Purpose of Inventories: It is hard to protect some things if you don't know they exist. Nearly all cave inventories turn up unknown or poorly understood features and processes. By discovering previously unrecognized human impacts, inventories identify gaps in monitoring, mitigation, restoration and prevention programs. High correlations between very common and less common cave features can help focus the search for rare cave features or ones that are commonly overlooked, such as speleogens. Inventories as well as good maps are essential for determining stratified sampling points, such as knowing where most of the dome pits are so that a random sampling of water quality can be taken from an adequate size group of dome pits.

Priorities: Inventory priorities should be based on a sum of 1) significance of known human impacts (coverage, bottlenecks, rarity, T&E status, etc.), 2) projected and/or postulated human impacts, and 3) lack of knowledge. #1 should have double the weight of #2 and #3. Consider #2. Most caves are low energy systems while humans are a high-energy species. Consequently, monitoring high energy human impacts often should have priority, such as the effects of trail erosion, vandalism, tunnels, and increased organics, light and vibrations in the cave, and human-caused disturbances above the cave or within its watershed. An important first step for #3 is to document the status of each park's knowledge so that important gaps in that knowledge can be identified.

Size: A comprehensive inventory would never be used for a single cave or cave system but items could be chosen relevant to a particular cave and set of management concerns. Field testing indicates that 100 items is the maximum that can be done at any one time without significantly degrading data due to fatigue. The much larger number of items in recently compiled inventories allows each area to choose items pertinent to their needs yet allows some cross-cave comparisons between different areas for those inventory items held in common.

Selection: Even using a very restricted inventory helps to determine when more detailed and/or quantified inventories are needed as well as determining cave significance, such as using a simple threshold number of items present or using more complex indices similar to those used in determining biological diversity or integrity or ecological value. The latter could be determined on the basis of how natural the cave is, its rarity, and its diversity (Ammer & Utschick, 1982). A certain score on a very cursory inventory could then indicate that a more detailed inventory needed to be done. A cursory inventory would also help in determining what to list on a more comprehensive inventory. Garton (1984) discusses cost-efficient inventories.

An inventory list structure can be developed with 1) use of common terms with secondary definitions if terms overlap, 2) subdivisions so that no or very few categories have more than 10 or so items, and 3) duplication of terms in the list so as to increase flexibility and ease of locating items. Without commonly accepted definitions, symbology, and demarcations of what constitutes certain cave features, few comparisons between different inventories are possible.

Relationships: The main importance of the distribution of a feature is its relationship to other features. This is largely how processes are identified. The abundance of troglobites, bats, cave slime, white flowstone, staining, humidity, biofilms, sharp edged exfoliation, soil compaction, erosion, or vandalism near trails or artificial entrances can suggest hypotheses that can be tested through experiment, mitigation, etc.

Inventories can help differentiate cave features through both direct measurements and by differences in habitat and season. For example, there are dimensional discontinuities between microgours and rimstone dams as well as differences spatially (areas of laminar sheet flow on flowstone versus turbulent stream flow).

The absence of features in certain areas can reveal important data. For example, the absence of easily destroyed or removable cave formations in areas where they normally would occur may indicate vandalism. Negative correlations may give clues to speleogenesis, geo-mineralogy, etc.

Frequency: Inventory items should be divided into those that only need to be inventoried once and those that need to be done more than once, especially air, water, and biological items. Even some speleothems, such as cave rafts and humidity-dependent minerals (mirabolite/thenardite, epsomite/hexadrite, etc.), can be present or absent depending on humidity, temperature, evaporation rates, etc. and therefore necessitate at least two inventories (winter/summer) or four, one for each season.

Scale: Establishing extensive monitoring within infrequently visited caves may cause greater impacts to resources than the limited visitation. The magnitude and detailness of the inventory and monitoring process also depends on the size of the cave or cave systems, past data accumulation, predicted or observed human impacts, and the amount and training of people who do the inventories. The latter factor can range from comments on registers by cavers, to use of whatever volunteers are available, to weekend caver projects, to monitoring projects by volunteer groups such as CRF, NSS, EARTHWATCH, Earth Corps, etc., to contracts with research grade scientists. At what detail a particular inventory needs to be done will largely determine which people can do the inventory.

Quantification: An inventory where a feature is only noted as being present, as opposed to a quantifiable inventory, has many disadvantages. For example, human-caused changes cannot be detected by a present/absent inventory until a particular feature has been completely wiped out in a part of a cave monitored after the initial inventory. The disadvantages of quantifiable inventories are that they are time-consuming and can yield false conclusions. Most minimal inventories should note whether an inventory item is absent, rare, or common. This minimal quantification may be the limit to reliability for certain cave features. However, many features can be quantified where the limits and units are greater than 10%, 30%, 60% and 90%.

Dimensions: The shape of a cave feature should largely determine how it is quantified. Point features, such as hydromagnesite balloons or bats, can be counted. Linear features such as rimstone dams can be measured linearly. Flowstone has surface area and sediments have volume. In general, the more dimensions used, the less accurate will be the dimensional estimates. For example, even with test pits, construction rubble volume to be moved during cave restoration is often underestimated.

Bias: If there is a great disparity in the volume of the inventory units (such as around survey points) then biases affect statistical analysis of distribution patterns of various cave features. A square foot coverage of certain features, such as flowstone, can overemphasize the effects of large rooms. A percent coverage can overemphasize the effects of small rooms. A combination of the two methods may have to be used.

Descriptive Inventories: An alternative to a checklist inventory is to be more descriptive (House, 1995). Features are noted and then tied to survey stations rather than the reverse method as is used for checklists.

Pros and Cons: One advantage to this method is that it takes less time than using extensive or quantifiable checklists. Time is not wasted learning the descriptions of rare features and checking for rare cave features unlikely to occur in a particular part of the cave. Another advantage is that undescribed and unlisted features are less likely to be lumped with listed and described features. Quality control can be difficult with the checklist format since anyone can make a check mark whether it is appropriate or not.

Compared to a checklist inventory, a disadvantage of a more descriptive one may be that distributions and common features may not be recorded. Unusual or noteworthy features may be those features most likely to be noted. However, if you don't know what you are looking for, you may not find it. Correlations may not be possible and bias could increase. A great deal of information can be gathered by a descriptive system in a short period of time but that information may not be very useful until that information is classified, quantified, and linked to a GIS.

Descriptive inventories may be best for basic inventories or for noteworthy features while more detailed and specialized inventories might use quantatitive checklists. The best inventories also balance between description and genesis of the items covered.

Location: Detailed maps that can be easily accessed, modified, layered, etc., are the basis for all cave inventory and monitoring and have to be done without the use of a GPS. A great deal of contextual information is lost without precise location of sampling sites. Materials such as bones and artifacts may have to be removed from a cave for analysis. Without detailed maps and directions, they cannot be returned to the precise cave conditions that have preserved them for so long. For example, placing a fossil bone just inches from its original location can put it in the path of increased airflow, condensation, and subsequent deterioration.

AUTOCAD or an equivalent program should be used (see the mapping section). The least utilized person employed in mapping can also be doing inventory or monitoring during the mapping project.

Points around which inventories are made should have markers that will stay in place and last long enough until detailed map sketches can reduce the need for such markers. Some or all of the markers may have to be retained, especially if certain inventory units have no natural, fixed feature point that can serve as a marker to locate sampling sites, photo points, etc.

All marked stations should be inventoried up to halfway to all other stations, both vertically and horizontally. This involves finding such sequences in the cave before any inventory can be done. Obvious alcoves or side leads that can be entered by a person will have their own separate station. Both sides of the tag should be checked to eliminate ambiguity and read the station correctly.

A no. 2 pencil or mechanical pencil with HB lead should be used. Data should be written plainly and darkly enough so that legible photocopies can be done. The station number and letter should be recorded exactly as they appear on the tag. All lower case letters should be recorded as lower case letters (only halfway up to next line) and all upper case letters should be recorded as upper case letters (all the way up to the next line). On the tour route, tags can be painted and may lack flagging to make them less conspicuous. Sequential station numbers should be followed. An incorrect station No. should be crossed out with a single line and a correct one added beside the incorrect No.

Once the inventory is completed, a check should be made to make sure all blanks have been filled in. The tags should be marked in some way to insure that the station is not inventoried again.
Where possible, data entry from the original survey form should follow closely the recording of field data.

Other data bases should include a list of inventory equipment and companies, a list of map symbols for many of the inventory items, and a list of addresses of those individuals conducting or knowledgeable of specialized or detailed cave/karst inventory and monitoring, cave visitation data, and a bibliography.

The following is the most basic of inventories needed to manage and mitigate human access and impacts to caves.

Cave Classification: Since human safety is a prime NPS concern and rescues can impact even sturdy formations, access to a cave or cave passage depends on the sum of its fragility and hazard ratings. A cave's rating may be changed seasonally, as a result of further inventory, or by the alteration or removal of a hazard or resource responsible for the initial rating. If it is determined that human use is adversely affecting cave resources, the zone category for that cave will be reviewed for possible change to a zone that better protects the cave.

Fragility 1 Caves and Cave Passages

Fragility 1 caves or cave passages contain resources that, due to their size or their location within the cave, are not easily subject to vandalism, disruption or destruction. These are areas in which frequent visitation by cavers or other visitors will involve an acceptable level of degradation. Examples include smooth flowstone that is not used as a trail.

Fragility 2 Caves and Cave Passages

Fragility 2 caves or cave passages have resources so positioned that they are vulnerable to breakage, disturbance and/or vandalism. Examples include tubular stalactites less than 1.8 meters (six feet) from the floor.

Fragility 3 Caves and Cave Passages

Fragility 3 caves or cave passages have resources that are of unusual quality or rarity and which are delicate and susceptible to disturbance, or areas for which no inventories exist. Examples include calcite needle clusters in the middle of a floor.

Hazard 1 Caves and Cave Passages

Hazard 1 caves or cave passages offer the least hazard to the caver. Hazard 1 characteristics include: (1) No known loose ceiling rocks. (2) Well-defined main passageways with only dead-end lateral passages. (3) No drops over three meters (10 feet).

Hazard 2 Caves and Cave Passages

Hazard 2 caves contain structural hazards not found in Hazard 1 caves. Class 3 characteristics include: (1) Maze-type passageways. (2) Vertical drops up to 9 meters (30 feet). (3) Loose rocks on ceilings over two meters in height. No known loose rocks on passages less than two meters (six feet). (4) Balanced rocks on uneven floor.

Hazard 3 Caves and Cave Passages

Hazard 3 caves or cave passages are potentially the most hazardous. Characteristics include: (1) Vertical drops over nine meters (30 feet). (2) Loose ceiling rocks in crawlways under 1.5 meters (four feet).

Zone 1 Caves and Cave Passages

The fragility/hazard sum is 2 or 3. These developed areas include most public use areas that provide visitors with comfort and convenience (e.g. hard surfaced trails, handrails, electric lights). No special clothing, equipment, knowledge or skills is needed. All visitors must be accompanied by Park Service staff.

Off-trail areas may be visited without a permit or Park Service escort. Excluded is the Cave, except for public caving tours by concession guides certified as a wild cave trip leader. Public use of caves will not be advertised or encouraged except for public tours led by certified concession guides or NPS staff.

Zone 2 Caves and Cave Passages
The fragility/hazard sum is 4. These areas may be visited by permit without an NPS escort. Permittees are responsible for providing their own equipment. Evidence of incompetence, previous cave abuse or disregard for park regulations are grounds for denying a permit. All members of the group will stay within the trail zone bounded by tape.

Zone 3 Caves and Cave Passages
The fragility/hazard sum is 5. These areas may be visited only when scheduled in advance and when the visitor is accompanied by a designated National Park Service trip leader.

Zone 4 Caves and Cave Passages
The fragility/hazard sum is 6. To obtain access, a collection permit must be approved by the Superintendent. The researcher must show in writing how potential damage to resources from research in a specific part of a cave will be more than balanced by knowledge gained that would protect park resources. Zone 4 designation does not exclude administrative entry to monitor research activity and impacts upon these caves. All newly discovered caves or cave passages will be initially assigned a Zone 4 designation.

Taping is an important part of both mitigation and future inventory and monitoring. Orange tape should be placed along the sides of trails or routes. Tape designating trails, should be placed in a way which clearly delineates between areas to be protected and areas to be traveled through. This can best be done by ending or beginning the line of tape at a wall or other prominent feature. Green or blue tape can be used for survey stations. White flagging will designate hazards, such as loose rocks, sudden drop-offs or other dangers. Detailed mapping and inventory should eventually eliminate the need for much of the taping.
Writing on tape with indelible markers can be used to locate "boots off" areas, the location of low, delicate ceiling features, and in areas of confusion, which side of the tape the trail is on. Routes may be altered if a more appropriate alternative is found.

Cave Name: When a cave has an established name, this will be retained. In the case of a cave without an established name, one will be assigned. Cave Markers: A brass cap will be set at the entrance of each cave. The cave name and park reference number will be stamped on the cap.

Monitoring is indispensable to determine desired conditions; to diagnose human impacts; to direct management intervention; and to measure subsequent success or failure of that intervention (Goldsmith, 1991). Inventories and monitoring may be used to detect correlations and pose research hypotheses to establish causal relationships, to evaluate the effects of management activities, and to develop and evaluate mitigation of specific human-caused changes.

Specificity: Monitoring must be hypothesis-based or driven by a "monitoring question," such as "Will this particular resource or process by significantly altered by present or future human-caused change?" Devoting part of the I&M program towards anticipating change is crucial because such research can be difficult and because prevention of human impacts in caves usually is much easier to accomplish than restoration.

Impacts: Monitoring occurs when the type and quantity of human visitation or other impacts is such as to warrant measurements that can be compared to baseline inventories. A monitoring system should be started in those caves with the most types of or adjacent to widespread human use both intentional and inadvertent. Monitoring efforts must be evaluated often to assure that selected monitoring elements are sensitive to human-caused change.

Scale: In general, monitoring is easier and cheaper when performed at lower levels of complexity, such as individuals or populations, than at higher levels, such as communities and ecosystems. Furthermore, results are easier to interpret and explain to managers at lower levels of complexity. Individual and population level effects of stress are likely to appear sooner than effects on ecosystem function, providing a better early warning of problems. Conversely, broader measures of ecosystem function integrate a variety of species and processes and detect changes that may be beyond the scope of a program oriented towards specific species. Observable changes in functional characteristics of an ecosystem may also be a more definitive sign of a serious problem than would be simple changes in species composition (Spellerberg, 1991).

Sampling, collecting, monitoring, inventories, and analysis beyond that of the more basic inventories is dictated by objectives, cost limitations, and the intensity of research needed to give useful results. It usually requires the supervision of or should follow established protocols from researchers listed by their areas of expertise (see Roth, 1995). The following covers more general considerations.

Air in large volume caves with small entrances is driven by barometric changes and, to a lesser extent, by geothermal gradients if there is a great vertical extent to the cave. Caves with larger entrances can have cold traps if the entrance is near the cave's top. Entrances near the top and bottom of a vertical cave have chimney and reverse chimney airflow.

Other airflows are minor and usually do not need to be monitored. Microscale disturbances in the atmosphere range from three seconds to three minutes and include microbaroms, those arising from sea storms. Others include falls, earthquakes, & cave resonance (all 1 sec. or less), volcanic and man-made explosions and other noises. Cave resonance ("cave breathing") can occur from outside winds perpendicular to the entrance, waterfalls, or surface atmospherics. Water flow can create minor airflow. Any removal or addition of material from or to a cave changes barometric airflow by changing the total volume of a cave. Usually this effect is very minor for the cave as a whole.

Changes in airflow often are the greatest and most widespread human impacts on developed or breached caves, especially on bats, cave-adapted arthropods, and both speleothem and speleogen formation and continued growth. Desiccation, corrosion, and/or frost damage to cave formations can result.

Recording airflow past and present can involved both inventories and direct measurement of various air columns in a cave using small amounts of smoke sidelighted and/or very sensitive anemometers. Helium, radon, and ethyl mercaptan has been used in broader studies.

Inventories of directional coralloids, eucladioliths, phytokarst, prehistoric frost exfoliation and debris, case hardening, aerosol sinter, anemolites, cave ghosts, moonmilk distributions, and previous bat roosts may be needed to determine the prehistoric extent of cave openings, airflow, and the extent of the associated zones (twilight zone, variable temperature zone, etc.). Eucladioliths are tube-shaped calcareous deposits oriented toward the source of light in a cave entrance and formed by encrustation of growing mosses, algae, etc., by organic sinter. Phytokarst occurs where algal attack produces randomly oriented spongelike surfaces like lacework. Radon deposited deep in flowstone can record the amount of prehistoric air exchange with the surface atmosphere over time spans of hundreds of thousands of years.

Airflow patterns and regrowth measurements of broken speleothems are helpful in determining which areas of cleanup should the highest priority, ie., those windy areas where calcite crystallization is most likely to trap in flowstone mud spread by cavers. Regrowth calcite from formations dated as to their breakage can be used to calibrate dating of other formations by uranium/thorium, etc.

Local additions or removal of material within a cave can change airflow patterns within that area, especially if the passages are small. Changing the size and location of the entrances can alter upward airflow in winter and downward airflow in summer. Air pollutants, organic deposition, atmospheric corrosion, condensation, visibility, and radon may also increase or decrease from airflow changes.

Carbon dioxide impacts from airflow changes, human breathing, and global increases in the last century can greatly impact caves. Much formation deposition and solution is controlled by a delicate carbon dioxide balance; such balances are disrupted by airflow changes. Increased carbon dioxide in the atmosphere probably will favor increased exotic plant growth as well as total plant growth on the surface. This could result in increased carbonic acid reaching caves, which in turn could dissolve formations at upper cave levels and increase formation growth at lower levels. Acid rain could have similar effects. Vegetation patterns may be affected, with efficient Co_2 users (CAM, C_4, etc.) and other slow growing plants outcompeted by less efficient users of carbon dioxide.

Carbon dioxide concentration in caves depend largely on the source and how much mixing with outside air occurs. Sources include degassing from incoming water (especially in vadose shafts), rotting of organic debris and, in some cases, from large bat populations or from deep seated hydrology such as the reaction of sulfuric acid with carbonates. Identifying sources can be helped by three factors: 1) radon gas production occurs at a fairly steady rate, 2) radon and carbon dioxide gas sources usually are separate, and 3) mixing with surface air somewhat equally affects both gases. Therefore, changes in radon concentrations can be subtracted from carbon dioxide changes to arrive at changes in carbon dioxide production. Most caves appear to have the greatest carbon dioxide production during the greatest input of dissolved organics. This normally occurs in late spring or early summer during summer droughts or in mid-summer with more evenly distributed rainfall.

The low exercise level involved in most monitoring can make carbon dioxide a hazard if levels exceed 2% for exposures of more than 12 hours, and 3% or higher for shorter exposure times. A butane lighter won't light at concentrations of 4% or higher. Symptoms and signs of metabolic alkalosis (high blood Ph) are pale and clammy skin, feeling of coldness, constricted pupils and irregular heartbeat. Written justifications should be made for entering a cave if the know concentrations of carbon dioxide are 1% or higher.

Air pollution can effect caves both by precipitation scrubbing and subsequent hydrologic entry through soils and by direct passage of air pollutants through cave passages and their subsequent attachment to moist walls or affects on atmospheric corrosion and visibility. Measurements of air pollution when the cave is exhaling and inhaling can help determine how much pollution is being absorbed by the latter process.

The amount of airborne organics, whether natural or otherwise, can be estimated by sampling with open glass petri dishes placed in areas not accessible to animal disturbance. Seasonal sampling could help distinguish between human and other organic sources but the usual slow deposition rates may only allow sampling of annual or longer durations. Firing glass petri dishes can help determine organic/inorganic ratios of the deposited material.

Evaporation rates and whether or not they correspond with extant cave features can be determined through geologic inventories of evaporitic minerals, the use of evaporation pans, and calculations dependent on knowing wind speed, air temperature and volume, etc.

Cave radiation is caused primarily by radon 222. Some additional radiation is generated by radon 220 (Thorium). Working levels of alpha radiation should be measured from the radon daughters and exposure records should be maintained for all employees. Inventory procedures should be followed as specified in the NPS Cave Radiation Safety and Occupational Health Management Guidelines (NPS-14).

Ionization has been little studied in caves but it likely affects condensation-corrosion and radon concentrations. Crystallization rates and distribution may also be affected.

<u>Biological</u>: **Basics:** The most basic inventory should be a list of at least 90% of species present. A graphing of number of species found over time versus the amount of visual searches, etc. can indicate approximately when that level is reached. The low-density sites commonly found in caves generally require more sampling than high-density sites to accurately assess species richness. For example mussels may require 200 samples

at lower-density sites compared to 40 samples at high density sites (Miller & Hartfield, 1988).

A good inventory also includes habitats and map locations in which biota are found, a trophic level list, the measurement of abiotic factors, and the identification of seasonal trends in populations (Braithwaite (1984) and Chamberlin (1981)). For small vertebrates see Cooperrider, Boyd, & Stuart (1986); Halvorson (1984), Taylor & Friend, (1984), and Yahner, et.al. (1994-5)).

Collecting: A reference collection can be maintained as long as it is part of the park collections. Otherwise, photographs and drawings are needed, especially in visual searches so that only the minimum number of individuals needed for identification of a unknown species need to be collected. Extensive consumptive sampling of the small populations usually found in caves can be devastating. It is not always practical to maintain voucher collections at parks. Cooperative aggreements should be developed with local universities or museums that meet curatorial standards for voucher and type specimen care.

Because small and moderately sized caves appear to have high extinction/extirpation rates, a collection of individuals of the same species and with very uniform morphologies may suggest the need for genetic testing. Some cave species have undergone recent near-extinctions or migration into caves in low numbers. Species near their range limits also tend to speciate. The result may be low genetic diversity for many species and a low ability to cope with human-caused changes.

Birds: Cave swallows in Carlsbad Caverns have been monitored for over 20 years.

Mammals: Small terrestrial mammals can be captured using Sherman traps. Trap treadles should be standardized to respond to weight of the smallest species to be sampled. More than one trap should be placed at each sample point. Where caves permit, trap grids should be large (e.g., 10-12 hectares); spacing between trap clusters can be "adjusted" by sampling different points on different days; e.g., with 30 meter spacing sample each point every other day by rotating traps as they are checked. Variation due to trap placement (a meter or less may make a difference even when traps are "selectively" placed at the most propitious points around the point) can be accounted for by measuring simple variables at each trap) Distances between subsequent recaptures can be used to weight estimates if the actual area sample cannot be determined. If catch/effort indices are used (instead of estimated numbers) corrections should be made for "sprung" traps (American Society of Mammalogists, 1987; Halvorson, 1984; Fellers & Arnold, 1988).

Other sampling techniques include track boards (for medium sized mammals), pellet counts, and nest/den surveys. Scat shape, size, composition, and fungus content can reveal the identity of many species and the age of the scat. The extent of darkened scent trails and the thickness and decomposition state of amberat can help in determining past and present use by woodrats in particular. Telemetry does not work well in most caves.

Bats require I&M methods different from other small mammals or from birds (Krzanowski, 1971; Kunz, 1988; Thomas & LaVal (1988)). Transmitters and tags with extremely low damage rates have been developed.

Photomonitoring of roost sites and guano piles can be done when bats are not using a cave. The decomposition stage of guano piles will indicate activity history and can range from distinct pellets, to what looks like dark soil, to the localized presence of phosphate minerals or mineraloids such as brushite, carbonate-fluorapatite, carbonate-hydroxylapatite, crandallite, guanine, hydroxy(l)apatite, monetite, phosphammite, and whitlockite. Such deposits sometimes can be paired with overhead roosts sites which can display dark staining, claw scratches, dome enlargement, and atmospheric corrosion. Abundant mold and macro-invertebrates indicate rather fresh guano. A synthetic (non-cotton) netting like bridal veiling should be cleaned off each time before a deposit forms which "cements" the sheet to the guano pile (Buecher & Sidner, 1995:314).

Bat surveys can be hazardous unless precautions are taken against bat bites, airborne rabies, guano dust disturbance, guano fires, ammonia fumes above 30 ppm, and fungal diseases listed elsewhere.

Bats and birds can be easily injured in mist nets; nets composed of vertical nylon filaments may cause less injury (Cross, 1986). If visual counts can be adequately correlated with ultrasonic bat counter recordings, then the latter can be set up all night to automatically record the number of bats entering and exiting entrances. Dense bat migrations may require computer analysis of videos, as has been used at Carlsbad Caverns (Fletcher, 1985). Assessing population change is best done with a combination of methods, such as combining band recovery with census estimates (Stevenson & Tuttle, 1981; Willig & Selcer, 1989).

Bats can be disturbed by lights, talking (especially whispering), and, to a lesser extent, by heat generated by lights or a passing tour and by high frequency noise from fluorescent light ballasts. When correlated with temperature and humidity changes, how often bat move around near tours compared to further away can indicate how much disturbance is occurring. The result of cumulative impacts can be sudden, as when a maternity roosts falls below a certain temperature as bats decline and is suddenly abandoned.

Herps: See Bury & Corn (1991), Bury & Corn (1983), and Jones (1986).

Arthropods: While invertebrates constitute about 70% of described species worlwide, the percentage in caves is likely to be over 97%. One estimate is that nearly half of the insect and arachnid species in North America remain to be described (Schaefer and Kosztarab, 1991). The percentage of undescribed cave and soil species is likely to be even higher. Because of opportunistic migrations, semi-permeable dispersal barriers, rapid speciation, etc. even adjacent caves with similar biological habitats may have very divergent biota. Several small caves may well have a greater total biodiversity than one large cave.

Sampling is covered by Southwood (1978) and Sampling in order to develop a species list often can be a mix of methods. Plastic cups 16 oz. or smaller can be baited with limburger cheese, rolled oats, feces, rotted meat, etc. Baited traps can attract large numbers of individuals and species, especially those low on the food chain and non-troglobitic. Preservatives such as ethylene glycol should be used only if past studies indicate that populations will not be significantly affected. Antifreeze with green dye should not be used as it may affect waterflow dye tracing. Visual searches and passive traps are more likely to proportionally sample predators and troglobites. Passive traps should have funnel shaped inserts to prevent escape and normally should not be left in a cave for more than 24 hours.

For each species, only a few individuals need to be collected for proper identification by taxonomists. This allows for variation in morphology, the inadvertent collection of non-adults, and for the collection of both sexes. Some species can only be identified from one sex or with a particular instar. If the species has not been previously described, a series of instars may be needed. Only a single specimen of each species may need to be collected during the first part of an inventory.

The most efficient technique to sample invertebrates, especially the very small species (<5mm) is to extract them from the organic matter and soil in which they live. These usually are endogena, species who live in the soil and occur sporadically in caves. Sampling of includes Evans (1986) for crustacean zooplankton; Fellers & Drost (1991) for mollusks & arthropods, Hawkes (1979), Metcalfe (1989), and Miller & Payne (1988) for aquatic invertebrates; Ishida (1990) for copepods; Mangum (1986) for macroinvertebrates.

The advantage of flotation over Berlese is you do not need a large sample and it is much more efficient than Berlese (Walter, D.E., Kethley, J., and J. C. Moore, 1987; Kethley, 1991). Flotation won't work for the guano of insectivorous vertebrates. If at all possible, organic material should be returned to the site of collection after extraction. /

Protists: Little recent I&M has been done on protozoa in caves or elsewhere (Carlough, 1989). Evans (1986) presents sampling methods for rotifers in oligotrophic waters often found in cave. Planaria often appear to be restricted to single cave systems and the same could be true for other protists.

Bacteria: Sampling for chemolithotrophic bacteria should concentrate on sulfur, manganese, iron, or other unusual deposits. Chemolithotrophic are chemotrophs that get their food oxidizing inorganics. Chemotrophs derive their metabolic energy from chemical reduction or oxidation of inorganic substances, such as sulphur or iron minerals. Sampling for chemoheterotrophic bacteria should be done in pools, soils, and on speleothems, especially moonmilk and flowstone. Speleothems near entrances and moderate airflow often have bacteria because they are sites for colonization by airborne microbes, incoming dissolved organics, and/or their subsequent concentration by evaporation. These and other wall species may be rare or absent elsewhere in the cave. Natural wallrock bacteria can occur in areas where aerial organic particulates and seasonal condensation coincide. Chemoorganotrophs such as *Leptothrix* often are slow-growing native bacteria found in unpolluted waters and can be easily extirpated by human activity. Chemoorganotrophs get their food by oxidizing organic compounds.

Bacterial sampling should focus on potential hazards to humans, including those involving fungus, hantavirus, plague, rabies, tetanus, ticks, & tularemia.

Sampling will likely record a minority of the species present. An incubation for at least 48 hours in a cave may enhance the number of species that will grow on a given enrichment. In caves with stable, old pools, sampling may have to be extensive because of speciation and resultant endemism within individual pools, as may be the case in Lechuguilla Cave.

Fungi: Low Ph in areas rich in organics favor fungal growth. Microbial sampling requires aseptic techniques to insure that what is cultured actually came from the cave. Most fungi exist in deep cave zones only in spore form, but occasionally actively growing fungi are found on recently introduced organics or in areas where spores have been introduced by cavers. Sterile rayon tipped swabs with a Stewart transport media culture tube can be used. These swabs can be inserted into soil or rubbed gently across other surfaces to sample fungal spores. Another technique is to aseptically expose petri dishes filled with potato dextrose agar to culture airborne fungal spores. Care must be taken not to contaminate the media with spores brought in by the samplers; filter masks should be used. Identifying fungal hazards likely in your area is important and can include cryptococcosis, histoplasmosis, mycormycosis, and valley fever.

Habitats: The condition, extent, and location of each major habitat should be inventoried, especially Entrance, Twilight, and Dark Zones. The Twilight Zone can contain threshold species found nowhere else in the area. The Dark Zone can be further divided into diurnally variable temperature/relative humidity, seasonally variable and relatively constant zones. Inventory systems used for forests may be helpful in determining habitat relationships (Dedon & Harret, 1982).

The focus in the Dark Zone should be on humid and organically rich areas, such those with bat roosts, flood debris, thin ceilings, or lint. Visual inspection of habitats should include organic material (leaf litter, wood, guano, feces, carcasses, roots, etc.) as well as different substrates (soil, under rocks, cracks, crevices, flowstone, pools). As most invertebrates are less than 10 mm long, a magnifier such as the OptiVisor can help one spot the smaller species.

Cave streams can be sampled with a combination of visual searches, plankton netting, and pumping/filtration for benthic (bottom dwelling) species. Mammoth Cave plans on sampling selected cave streams every seven years, a compromise between the need for data points and minimal researcher impact on the resource.

Abiotic factors to be measured include air and substrate temperature, Ph and depth of pools, relative humidity, water and air flow, light intensity, and vertical heterogeneity. For example, the timing and intensity of floods is important in both mortality and the replenishing of organics. Temperature conditions are important for cold-dependent (cryophilic) species such as grylloblatids. In other cases, mineralogy and sediment relief, chemistry, moisture, stratification, and the volume of the habitat are important.

Mapping hydrologic contacts may be important in locating genetic interchange which may only occur when flood events connect two normally separate drainage basins. Such interchange may be in part be why aquatic cave species show less endemism than terrestrial cave species. Mapping helps delineate the effect of abiotic factors on biology by locating habitat fragmentation, surface land use, etc.

Ecologic type: More advanced inventories should include distributions in time and space of troglodytic, troglobitic, endemic, rare, indicator, T&E, exotic, heroic (charismatic), keystone, disjunct, hazardous, human-impacted, dominant, disturbance-dependent, social, extirpated, widespread, range-limited, and otherwise important species. Also included should be proportional representation of different physiognomic types (e.g., bacteria, invertebrate, vertebrate) and species named in enabling legislation.

Guilds: A guild is what an animal does (Block, Brennan, & Gutierrez, 1987). These include bandits, batellites (incl. guanophiles), detritivores (both guanobias & scavengers), fungivores, heterotrophs, parasites (including hyperparasites), phoretics, predators, and xylophages. Bandits are marauding cavernicolous predators and scavengers who plunder the resources of communities which inhabit guano beds, but who live mainly in other cave microhabitats. Batellites are dependent on bats. A guanophile is ultimately dependent during at least part of its life cycle on guano. A xylophage is an animal which consumes wood either to digest lifeforms on the wood and/or to digest the wood with the help of mutualistic protozoans and bacteria.

Documenting functional roles of species is important is determining which species are most at risk from human-caused change. A subdivision of guilds describes interrelationships with other animals and includes commensalism, mutualism, parasitism, phoretics, predators, & symbionts. Inquilism is a type of mutualism in which one organism lives inside another. A phoretic appears to be parasitic but is simply on another animal for the ride. It is neither commensual nor mutualistic.

Only a few examples of the importance of inventorying ecologic types can be given:

Predators at the top of the food chain are vulnerable to biomagnification of pollutants while long lived species, common in caves, are at risk from bioaccumulation of pollutants.

Troglobitic species often have reduced waxy cuticles, slimmer and more transparent bodies, and extended appendages compared to their more surface-adapted relatives. This makes increased absorption of some pollutants or heat from artificial lights more likely.

Indicator species such as isopods or fish can be used to establish indices of biological quality (such as pristine or exemplary) or integrity (Crumby, et.al., 1990; Dallinger, Berger & Birkel, 1992; Hawkes, 1979; Karr, 1991; Metcalfe, 1989). Other indices include stability, persistance (Connell & Sousa, 1983), resilience (Kelly & Harwell, 1990), migration rates, sensitivity to pollutants, etc. Invertebrate groups with short generation times, high biodiversity, and rapid population growth can help detect biologic change. Invertebrates have been used to look at the effects of dissolved oxygen, heavy metal, and turbidity levels. When correlated with water quality, the ratio between surface species and interstitial and karstic species can be used as an index of pollution.

Guanophile distribution can record both past and present bat activity. They often are the first arthropods affected by humans in caves because so many bat colonies are so easily disturbed by humans. Cave species most at risk from long-term extirpation are poor colonizers, like most mammals and endemic cave arthropods. Most interstitial fauna, bacteria, and fungi tend to be rapid colonizers.

Social species can had critical threshold populations below which maternity roosts, mating swarms, predator avoidance systems, and so on fail and all individuals may die or move elsewhere.

Timing of sampling should ideally cover two years so as to better differentiate seasonal versus longer-term or "random" changes. Major controls on populations include changes in organic input and relative humidity which in turn are largely dependent on outside rainfall and temperature change. Hawaiian lava tube troglobites, for example, have a diminished ability to withstand desiccation. Caves with strong seasonal airflow tend to have migrations away from entrances with inflowing air and into more humid areas such as small cracks.

Populations of most importance are those comprising species types listed above as well as those of type localities and those that change greatly. Capture, marking, release, and recapture methods in random stratified sampling of appropriate habitat are the best way to establish population distribution and change. Visual searches using quadrants and mouth aspirators are much quicker but produces more limited data.

Parameters such as age, stage, size-class structure permit projections of future conditions of recruitment, mortality, and productivity. Interspecies comparisons using this type of data can help map out the effects of competition, parasitism, predator-prey relationships, habitat size and quality, and human impacts on community composition. Such data can provide early warnings of pending problems. The caveat is that even the fairly simple ecosystems found in most caves are not as orderly as was once thought and therefore require considerable data before consistent patterns, if any, can be discerned. Dawson (1981) reviews the usefulness of absolute and relative sampling measures of abundance.

Because of the small size and low-food habitats of most cave species, measures of biomass and productivity are helpful in identifying potential energy bottlenecks, nutrient pools, limiting resources, and other critical controls on populations. Except in caves with large amounts of woody organic matter, invertebrate biomass likely predominates. The effect of depth from the surface is important, especially if the main food source is dissolved organics from diffuse flow. In this case, depth may have a peninsular effect (Milne, 1985). Deeper parts of a cave are more likely to be affected by human-introduced organics than those areas closer to the surface.

Stress: Human impacts may be detected by mobile animals vacating a cave, an drop in evenness or biodiversity (especially troglobitic and keystone species), and an increase in filter feeders (tubificid worms, rotifers), sewage bacteria, exotics, or predator/prey ratios. Evenness reflects the variations in species relative abundances, and is independent of the species count, or richness. Essentially it is a measure of community organization (Odum, 1985).

Subtle, chronic stresses are often reflected in reduced growth and reproductive rates (Odum, 1985). Population variability and an increase in the r-selected/K-selected ratio have been widely correlated with population stress and instability. Previously filled climax community niche space is subdivided by perturbation or stress. This open niche space is then saturated by other non-climax species. Original influx of pioneer and mid-successional species temporarily inflates both diversity and species richness. As disturbances effects compound, the number of species that can coexist with the disturbance decreases. Frequent, high energy stress of long duration can erode cave communities completely (Freedman, 1989).

In species-poor habitats, as are most caves, the introduction of exotic species may result in rapid loss of native species and a high success rate of exotic introductions. The fire ant in the Southeast is a good example. Migration into most caves is slow and as a result vacant niches are likely to exist that can be filled by exotics.

Although biodiversity often is thought to be species specific, all levels from genetic to community/ecosystem diversity should be considered. The number of species coexisting within a uniform habitat is termed alpha diversity and is often the only one considered by cave managers. As habitats change along micro-climate or organic richness gradients, new species are found as other species drop out, and this species turnover rate is termed beta diversity. It can be high if a strong gradient exists in a particular cave, such as rapid changes in temperature, relative humidity, or organic content.

Theta diversity also can be high in caves. It is the rate at which additional species are encountered as geographic replacements within a habitat type in different localities. As caves are degraded and fragmentation "progresses," it is first the theta rarities (local endemics) that become endangered and are lost. This happens first in regions with the richest cave biotas, as in the Southeast and Texas. Comparing karstic basin, region, national, and global diversity can help identify diversity not yet adequately protected.

To identify which changes actually signal trouble, managers must know the normal cycle for a community, especially in newly discovered caves or the most pristine areas of an already impacted cave. For example, in some simple food webs found in caves, population densities may oscillate as they return to equilibrium. Population-growth rates are the single most important variable in predicting whether a population will remain viable in the future. The lower the growth rate, the more slowly average persistence time increases with population size. If cave populations consist of a hundred individuals or less, demographic uncertainty in terms of unbalanced sex ratios, uneven annual population growth, food availability, etc., can cause extirpation of that population.

Knowing about natural variability can help detect whether there will be resonance from the match between intrinsic/human effects, thus increasing population oscillations to the point of extirpation, etc. Because of strong seasonality in food resources, even populations in more complex food webs dependent on guano or flood debris can fluctuate widely. Frequent and long term sampling is usually needed to map out such complex dynamics. Biodiversity is also strongly dependent on sample size (Kaesler & Herricks, 1977; Loehle, 1990).

Overall, heavy human visitation in a cave may have only a slightly negative effect, if any, on both cave adapted arthropods and entire community groupings (Carlson, 193:33). However individuals species may decrease (as in a troglobitic dipluran, (Crawford & Seenger, 1988) and many troglobites may become less common near trails (Crawford, 1994; Northrup, 1992). This could most likely occur in heavily visited caves where rapid changes in airflow or food sources causes migrations of arthropods subject to trampling. Biodiversity and populations levels in Hawaiian caves are inversely proportional to the level of visitation and human disturbance (Howart, 1983:57).

Based on size and variability of populations, a percent of disturbance that those populations can tolerate without being significantly impacted can be estimated. That percent can be drawn as a volume around major trails, underneath sewer lines and/or by altered entrance areas associated with that particular habitat. Sampling can then be done on and far from that volume's surface. Similarities in capture rates between same-habitat sites far and near the trail could then indicate whether or not human-impacts are having significant impacts on cave arthropods. Populations with very restricted habitats or with very uneven distributions may have to be sampled by age classes, etc., in order to access the effect of human impacts.

Organics: Dissolved organics and a soil survey help determine the relative effects and ratios of human-caused and natural organics in a cave's energy budget. PO4, NO3, NH4, NHO3, NH3, Nox, toxic metals (chromium and copper), and dissolved oxygen concentrations can be inventoried at drip and stream sites if water quality degradation or nutrient bottlenecks are suspected. A soil survey can be combined with dye injections.

Organics not native to caves can include exotic plants, lint, skin flakes and oils, trail asphalt, wood or epoxy, and more airborne particles from entrance changes. All may cause cave animals adapted to food poor environments to be outcompeted by surface adapted, opportunistic animals. Cave-adapted macroinvertebrates tend to avoid foot traffic vibrations and an increase in light, noise, and heat caused by public tours. The effects on resident populations of removing human-caused organic debris should be monitored. Important ecologic parameters to measure include decomposition rates and the ratio of living/dead organic matter. Biotic distributions in caves are often determined by the state of decomposition of organic matter.

Decreased organic input into caves can cause as much impact as too much organics. Because soil organic input in a cave may only be a few percent of what occurs on the surface, food is the limiting resource for many species, including troglobitic ones. A decrease in the predator/prey ratio can indicate that soil organic input is decreasing, such as normally happens in the conversion of a surface forest to a grassland or parking lot.
Increased discharge from these or other human impacts can flush organics out of a cave instead of depositing them. Aquatic cave gates can prevent organics from reaching a cave.

Cave pools with human-caused organics can be monitored by measuring dissolved oxygen, especially during times of heavy organic input and/or lack of convective overturn in spring and fall. Biological oxygen demand (BOD) of pool bacteria is an easy way to detect overall changes in bacterial activity caused by foot traffic, lint, lights, etc. (Bratvold, 1995). Bacterial populations in pools may peak when drippage equals drainage/evaporation rates and decline during overflow and low drippage times (Bratvold, 1994). To determine limiting factors, measurements can be made concurrently of nitrates, amino acids, short chain organic acids, nitrate, nitrite, ammonia, and soluble reactive phosphate.

Those caves with the greatest difference between natural and human-caused organic inputs, such as caves under desert areas, are likely those areas with the greatest human-caused changes in bacterial populations (Bratvold, 1994). Inventory of the percent coverage of visual cave slime and slippery biofilms can help identify trail impacts, airflow changes, and degradation in water quality.

Mitigation: Efforts to mitigate such impacts could include settling "ponds" and/or raising curbs to trap lint, reducing total wattage and the % of lighted areas, changing trail surfaces to reduce vibrations, restricting human traffic, etc. All such efforts need to be monitored to evaluate their effectiveness. Control over the number and timing of visitors on a trail is crucial to evaluating human impacts.

Plants: A three year inventory of percent coverage of exotic plants in the cave should help determine the frequency of hypochlorite spraying that is the minimal needed to prevent human-caused carbonate solution and/or substantial increases in biota attracted to the exotics. Estimating coverage by exotics should be done with strong headlamps; blue-green algae can grow in less than a foot-candle, what appears totally dark to people blinded by trail lights. The amounts of bleach used should be monitored thereafter and coverages estimated again if lighting or chlorox usage changes substantially. Two lights located away from the trail can be randomly placed to help differentiate the effects of lights and chlorox spraying from other trail impacts. Mitigation should include spraying only during periods of high airflow. Ph of adjacent water bodies should be monitored.

Cultural: Very critical is inventorying the exact location and description of artifacts that can be moved. In most cases, unless the possibility of vandalism or theft is high, most cultural artifacts and their contextual data can best be preserved in situ.

Archeological: Normally perishable artifacts such as those made of wood or cloth can appear quite fresh and well preserved in caves and may even be thrown out during cave restoration unless prior inventories have been done.

Dating by thermoluminesence relies on a fairly uniform buildup of electron traps that is reduced to zero when the artifact was heated as in some pottery and stone tools. The specimen to be dated is heated once more and the intensity of light given off by the release of trapped electrons is measured. One must also know the background radiation that stimulated the filling of the traps and the sensitivity to radiation of the material itself.

Racemization dating is based on the chemical racemization of amino acids, where an optically active amino acid over time is converted to a mixture of two isomers which possess no optical activity.

Markings: Modern graffiti may be difficult to distinguish from historic graffiti (more than 50 years old) or even prehistoric rock art unless a good inventory exists that precisely locates all markings. Graffiti not promptly removed or obscured induces further graffiti. A well-done inventory insures that only graffiti vandalism is promptly removed, not historical or archeological graffiti. All graffiti dated to less than 50 years ago may be removed unless there is a likelihood that a particular graffiti may become historically significant over time and is not being documented. However, letter styles and other criteria should be used to help establish the age of "new" historic writings or rock art because of the ease in which historic or archeologic items can be overlooked in past inventories.

No application (such as chalk) should be used in making rock art and writings more legible for photographic documentation, etc. Aluminum oxide may be used on non-porous pictographs if it can be shown that such a coating on an adjacent non-pictograph rock surface can be completely removed after the time required for documentation. The high porosity of many carbonates makes this unlikely.

Ethnography: Caves contain the homes, storage sites, shrines, burials, initiations, and refuges of native people. As gateways to the lower world in most native worldviews, caves often serve as critical markers of the cultural geography of many native societies. Associations may be with groups far from their cultural boundaries as drawn by anthropologists. Any main cultural inventory of caves should include consultations with extant native peoples, at least within an anthropologically defined region, and perusal of the ethnographic literature on culturally extinct groups. It is, of course, up to the native people, as to what information they are willing to share.

A comprehensive ethnography should include data on all people associated with a cave, including researchers, cavers, tour guides, etc. Visitor surveys are helpful in recording and predicting human behavior and its impact on caves.

<u>Geology</u>: **Dating** of features, coupled with location and speleothem ring inventories, helps to delineate the prehistoric timing and frequency of both solutional and depositional processes.

Bombardment of crystals by natural radiation leads to the trapping of free electrons in defects in the crystal lattice. The rate of trapping is determined by background radiation. The energy of the trapped electrons can be measured and a **electron spin resonance (ESR)** date derived from the ratio between this figure and the trapping rate. The internal radiation dose depends on the rate of uptake of radioactive isotopes; this can't be measured directly, but the date can usually be bracketed by certain limiting assumptions.

Unstable uranium atoms decay at characteristic rates to various different daughter products. Uranium 234/238 dating has had limited success in caves. The daughter product most favored for dating is Thorium-230 and the preferred materials for dating are freshwater-deposited speleothems. Since uranium is soluble in the water that deposits these limestones, whereas thorium is not, a newly forming stalactite will contain uranium but no thorium. As time passes, uranium will decay to thorium and the **thorium/uranium** ratio will increase and can be dated. Dense flowstone or dripstone with original depositional layers intact and abrupt termination of that deposition are less likely to be contaminated with newer uranium than are wet, porous speleothems, pseudomorphs, bones, teeth, shells, etc. The same holds true for isotopes of carbon in **carbon 14** dating.

Thermoluminescence can date speleothems up to 10,000 years old. Water can be dated isotopically and with tritium. Sediments and flowstone can be dated paleomagnetically both in terms of previous magnetic reversals and with more time specific changes in orientation of iron particles with regard to changes in the location of Earth's magnetic poles.

Color of formations and other cave surfaces can be discolored from smoke (torches, candles and/or carbide lamps), lint, skin oils and flakes, exotic plants, and dust from cave trails and the outside. Changes in soils from fire suppression, trail compaction, depth from the surface, atmospheric CO_2 increases affecting plant growth and patterns, acid rain, and how fast water reaches part of a cave may alter organic acids that color cave formations.

Phosphorescence is luminescence in which the stimulated substance emits light after the external stimulus ends. When correlated with other analysis, the intensity and color can indicate the amount of humic acids, iron, etc. Luminescence caused by walking on a substrate often is an indication of pollution.

Cleaned formations can be isolated from touching by changes in trail design. Then if the formation returns to a dingy color it is more likely to be a result of lint, dust, or mud droplets produced by trail traffic as opposed to the effects of touching.
Color charts can help quantify changes, such as how fast restored formations return to their original color.

Erosion: Human-caused erosion can occur by 1) freezing, dehydration and dissolving of formations from airflow changes, 2) touching and walking, 3) acids produced by lint and living or decaying exotic plants, 4) salts from hands, 5) electrical changes, and 6) increased or concentrated water discharge.

Only a few examples can be given. Salts can cause significant corrosion of handrail steel lacking in tungsten or titanium or associated with poor electrical grounding. Large amounts of aluminum gels have formed on electrical fixtures and upon drying have spread further into caves. Temperature changes in summer and precipitation events in winter have been implicated in ceiling rock fall in lava tube and marble caves, respectively. Especially hazardous are unconsolidated sediments, as in boulder or piping caves or where glacial deposition or resolution of cemented rubble piles has caused instability.

Rock stress recorders could be installed to monitor glacial surges and movement in joints. The recorders can document past geologic activity at specific sites, but they cannot predict where rock falls would occur. Rock fall and exfoliation is most common in cave passages artificially enlarged, rapidly formed (sulfuric acid), in glacier, piping, or boulder caves, or near the surface. However, exfoliation can occur naturally deep in a cave as a result of low Pleistocene temperatures. Such exfoliation normally will show calcite deposition and/or corrosion at its edges whereas human-caused exfoliation usually has sharp edges. Precise surface levelling, drilling, logs of drilling resistance, and deeply set telescopic bench marks and strain gauges can access the risk of increased ground surface instability as a result of either human or natural processes.

Exploration: Planned surface development and adjacent land use necessitate knowing where a karst system extends. Techniques that can detect changes in rock porosity and stratigraphy include gravimetric, acoustic, magnetic, telluric, resistivity, spontaneous potential, cone pentrometer, ground penetrating radar, and seismic (Roth, 1995). Simultaneous vertical and horizontal resistivity monitoring has been used to trace an injected electrolyte solution to confirm predicted flow paths and flow rates. However, most methods usually fail to delineate cave-size voids. Closely spaced drilling is the only reliable method but is likely to damage any cave encountered.

The best way to locate caves is by foot and with an understanding of local cave speleogenesis. Aerial photography using infrared or snowmelt areas can locate the exhaling of cave air.

Cave Formations: High on inventory priorities, especially in newly discovered caves or cave passages, should be any feature most at risk from human impacts, including those:

1) currently biogenic in origin (calcitic and aragonitic moonmilk, rust stalactites, U-loops),

2) most sensitive to temperature (fine-grained, wet calcite) or relative humidity (mirabolite/thenardite) changes,

3) most easily destroyed by physical impacts, especially those on the floor or low ceilings (floor gypsum rope, conulites, cave blisters and bubbles, moonmilk, broomstick & sand stalagmites, bottlebrushes, filiform heligmites, vermiculations, sinter, mud cracks, hoodoos, spitzkarren, shark

teeth & teat lavacicles, shelly or shark skin pahoehoe, balloons, & thin ribs, rims, and rimstone),

4) removable items (cave pearls, volcanic bombs, sparkly sediments, needles),

5) features easily overlooked (gypsum hair, some atmospheric corrosion, etc.),

and 6) rarities (subglacial crusts, hydromagnesite conulites, huntite crinkle blister flowstone, subaqueous helictites, quartz and selenite boxwork, flexible and subaqueous flowstone, cubic cave pearls, U-loops, etc.).

Mineralogy: Simple field techniques can inventory mineral groups into broad distributions. Once this is done, critical samples can be x-rayed, etc. for more definitive determination. In the field, only small, detached minerals should be tested and then put back. Calcite and aragonite fizz if 10% hydrochloric acid is added and can be scratched by a penny. Dolomite will fizz if powdered. Non-porous aragonite will sink in bromoform but calcite will float. Gypsum can be scratched by a fingernail and will not fizz. Quartz will scratch glass.

Various minerals, when correlated with other features, are important in determining past speleogenesis. Sulfuric reactions may be associated with celestite, sulfur, endellite, secondary chert, cave clouds, folia, ramiform caves, and extensive atmospheric corrosion fill. Mixing zones may have spongework, high salts, and honeycomb erosion. Hydrothermal action is associated with sulfur, barite, fluorite, logomites, metacinnabar, cupolas, and high geothermal gradients. Drought may be evidence by corbelled or broomstick stalagmites and efflorescences (gypsum, natron, halite).

Aside from breakage, staining, or removal, most human impacts on cave minerals are subtle, such as the transformation of calcite into aragonite from cave lights, the exposure and subsequent production of sulfuric aside from pyrite, and the gradual hardening of moonmilk from increased water flow. Transformation impacts may be detected by an inventory of pseudomorphs. Of special concern should be potential impacts on rare cave minerals such as metacinnabar, celestite, beaudatite, and cahlcophantite.

Sediments: Cave sediments can be dated paleomagnetically and can help identify prehistoric soils, surface and subsurface weathering and erosion rates, paleo-water flow direction, speed, and volume. Sediments can preserve fragile prints thousands of years old as well as serving as a source for ancient mud glyphs, etc. For inventory methods, see Irving & Bjornn (1985) and Stone (1986).

Sediments most critical for I&M are those that are dry and in the path of humans. Inhaling bat guano, volcanic ash, or toxic minerals such as metacinnnabar can be deadly. Lint deposition concentrates where air is moving upward, downward, through small, rough passages, or into large rooms. In fairly uniform and dry caves, the distribution of lint from the center of the trail can be measured by removing lint and then measuring a five year accumulation.

Because of the lack of biological or weather changes, cave sediment compaction from foot traffic often is permanent. Compacted sediments can concentrate runoff and subsequent erosion. They often have decreased particle size and will dry up faster during dry periods and thus increase dust being kicked up and deposited off the trail. This can increase radon hazards and, in extreme cases, directly decrease visibility in the cave and or indirectly by creating condensation fogs. Habitat for soil fauna may be lost as well. A rough estimate of the surface area of trail compaction can be had by measuring the depth of heelprints or the amount of pooling in a transverse perpendicular to a trail. Proper placement of both paved and unpaved trails can minimize the total area of compaction.

Paleontological resources are the only direct evidence of past life and as such are the basis for understanding the history of life on Earth and are an integral part of our planet's biodiversity. These resources are preserved as fossils which are any remain, trace or imprint of a plant or animal that has been preserved by natural processes in the earth's crust from some past geologic time.

Fossils are associated with caves primarily in two ways. They may be an intrinsic part of the rocks especially marine sediments such as limestone or dolomite, in which the cave is formed or they may be intrusive, having secondarily accumulated in cave passageways.

With regard to the second association of fossils with caves, caves often provide the only means of preservation of fossils in a region, especially places that do not act as areas of sediment accumulation. For example, bones that accumulate in lava tubes might not otherwise preserved in an area extensively covered with lava. As with other areas, the remains preserved in these caves may provide information on the presence of species, both plant and animal, and the past ecology of the area, that might not otherwise be available.

Depending on the region in which the caves occur, the nature of preservation may vary considerably. Although hard parts such as bone and shell are most likely to be encountered in caves, in the arid southwest organic material can include skin, nail and other keratinous material and dung. Preservation of this organic material is rare and especially vulnerable to being damaged.

In some caves with sediments in passageways or rooms, tracks may be preserved. All caution should be taken to ensure that traffic through these areas does not disturb or destroy the tracks. Tracks often will be in the same part of the cave floor that cavers would normally traverse.
Collection and removal of fossil material from caves should follow as closely all procedures outlined in NPS-77 for other fossil material with proper collection and documentation.

Given the special circumstances that exist in cave environments there are times when removal of fossil resources is paramount for their long term protection and care. As noted on page 157 of NPS-77, protection may also include, where necessary, the salvage collection of threatened specimens that are scientifically significant. In a cave environment some of the circumstances that may threaten a specimen include:

1. Caves often have narrow passageways which permit only limited room to maneuver. Because of the limited nature of these passageways the remains of animals are often found in the only available route for movement through the cave. Fossils in this position are extremely susceptible to damage by cavers walking or crawling through this passageway. The possibility of damage to the specimen is also enhanced by the limited light available and the bones way not be recognized as such by inexperienced cavers. In such circumstances proper collection of the fossils and removal from the passageway is imperative for their survival.

2. Fossil material often occurs loose on the surface of passageways. When noticed as to its nature often this material is picked up and moved to the side in order to "protect" it thus removing if from its original context. Small specimens way be moved numerous times, separated from related specimens and eventually may be lost or stolen. Improper handling can also result in breakage to the specimen. Specimens such as this are particularly vulnerable and should be properly collected, mapped, documented and placed in the park collections.

3. Fossils often accumulate in cave passages due to the action of water. Active streams in caves or streams that are seasonally active may uncover fossil material or bury material. Stream passages that are seasonally active have the potential to remove specimens or transport them to other portions of the cave system. Although a specimen may remain in a particular stream for long periods of time, an unusually wet year or higher than usual runoff into the cave may result in the loss of the specimen. Proper collection and documentation of the specimen should be considered.

Sediments that accumulate in caves may include the remains of small vertebrates or invertebrates, both of which may be important for understanding the local ecology. This remains may include animals living in the cave, eg. bats or may be the remains of prey brought in by predators such as owls. Deep sequences of sediments may preserve a significant portion of time that documents ecological changes in the vicinity of the cave. Recovery of these small vertebrate and invertebrate remains may require the removal of bulk sediment samples for processing.
Screening can help sort out bones that are somewhat larger than the silty sediments in which they commonly occur.

In all circumstances, the collection, removal and documentation of important specimens should be conducted under the auspices of a trained paleontologist working in conjunction with the park's cave resource management specialist.

<u>Temperature</u> changes result largely from airflow and, to a lesser extent, from water flow changes. Increased temperatures in cave water could reduce oxygen levels and spread diseases among macroinvertebrates. Compared to surface cousins, some aquatic troglobites have increased sensitivity to temperature fluctuations. Higher air temperatures near lights can alter calcite to aragonite. If sufficient organics are present, Ph and oxygen levels would decrease and calcite solution would increase.

Prehistoric temperatures may be determined by the ratio of oxygen isotopes in flowstone. The bedrock in deep caves can record long term temperature fluctuations.

<u>Vandalism</u>: An inventory should include a count of broken formations, regrowth measurements, classifications of breakage, and a photo and video documentation of a cave's formations and artifacts (Benson, 1983; Frantz, 1990).

Broken formations can be marked with a yellow grease pencil. A broken formation count should be conducted every two years after the initial one is completed. Only after two to three surveys will a fairly accurate baseline be established. Surveys should be done with headlamps since having tour lights on will most likely result in only partial coverage. A minimum size of broken formations is chosen, below which the breakage is not counted. Grouping of small, broken formations, such as popcorn, must be done. The diameter of the groups to be counted will vary from cave to cave but usually averages a few inches.

Vistas are measured using a system of fixed photopoints and/or videopoints established at selected sites within the Cave. Each site is marked with an unobtrusive identification tag and inventoried as to the nearest survey point. Distance and orientation to the nearest survey point and azimuth and declination the camera is pointing to, exposure information, and height of the camera from the ground will be recorded. Depending of the parameters measured, visitation levels, documented resource degradation, etc. phototransects should be repeated every two to ten years.

Even with this information, a slide from a previous inventory will have to be taken in order to position and frame the camera accurately. These photos and videos provide comparative qualitative and quantitative data for any resources visible within the photograph. ASA 25 speed color slide film and a 50mm fixed lens and the same flash unit will be used. The adequate Fstop will be established and two identical shots taken of each photopoint every five years. Alternating negative and positive transparencies and then combining them would indicate that nothing has been added or taken away from an area if the combined transparencies are totally black.

Water: Wherever water-borne pollutants constitute a threat to cave and karst resources, a watershed approach is usually best. Useful data sets include synoptic and flood pulse water quality sampling, correlative biomonitoring of these same waters, and acquisition of land use and demographic data for each drainage basin. Synoptic means taking taking samples at a fixed calendar date and time regardless of conditions. Information is needed from surface headwaters, cave waters, resurgences, and base-level streams wherever applicable. Design of an water quality program is covered by Flora (1984), Land Manager's (1991), Sanders, et. al., (1983), Smillie (1982), & Stednick, (1991), and US EPA (1986). Chemical methods are reviewed by US EPA (1983). The use of fixed stations versus intensive surveys is covered by Van Belle and Hughes (1983).

Cave aquatic systems are especially vulnerable to alteration by people and include indices of change relatively easy to measure. Ions, turbidity, Ph, temperature, discharge, and other parameters likely to be altered by human activity should be monitored periodically where feasible to quantitatively measure any change. The growth of cave features can be affected by temperature, evaporation, aerial deposition, pollution, flow routes and flow through times. Because karst waters show great variability in quality and discharge over time, more than one yearly cycle needs to be inventoried. Mammoth Cave uses an "on five year-off two year" schedule of synoptic sampling.

Of critical importance is the solubility index, to what extent the water is dissolving or precipitating minerals. This often is a delicate balance and may shift depending on seasonal, climatic, and waterflow changes. Temperature, Ph, and major ions (calcium, magnesium, and sometimes sulfate, chloride, sodium, and iron) need to be inventoried in order to calculate the solubility index.

Once cave waters have been grouped by their ion content, pollution, etc. a relatively easy and inexpensive method can be used to monitor future changes, such as the measurement of both Ph and TDS. If any major deviation of a particular water "signature" occurs, such as the Ph/TDS graph point of one type of cave water occurring in the point cluster of another water type, then a full analysis of major ions, total organic carbon, and long-chain hydrocarbons should be done to determine where the change is coming from. If long-chain hydrocarbons are detected, the more impacting polyaromatic hydrocarbons should be searched for. Biodiversity can also be used to measure pollution intensity (Verma, Sharma, & Goel, 1987).

Water temperature is a low-cost method of monitoring transport times and locating contaminants. A water temperature close to that of input sites would indicate rapid transfer and flow rates, a common result of human impacts on the surface.

If the original size of entrances cannot be determined, inventorying water and pool speleothem levels of pools both near and distant from cave entrances may help determine prehistoric relative humidity and water levels and the size of entrances at that time. Adjacent evaporimeters and analysis of the specific conductance of pool water and associated drips can help determine evaporation rates.

Sewer lines above or near the cave can be monitored yearly with special cameras for hairline breaks that otherwise may go unnoticed for decades.

Diffuse seepage usually occurs along bedding planes, as dry season inflow from sediments, and in proto-caves. Conduit flow occurs in cave streams, in vadose shafts, and through vertical joints, normal faults, etc. There is no sharp division and flow rates along the same path can change to either type depending on the season, etc. The more the water table follows surface contours the more likely water moves by diffuse seepage.

Flow rates can be determined by dye tracing, dissolved ion concentrations, and matching peaks in surface precipitation with peaks in speleothem drip rates. Location of flow can be determined by cave exploration and by more indirect methods. Waterflow creates an electric current whose potential gradient is proportional to the driving pressure. The voltage distribution on the surface corresponds to the horizontal component of the underlying waterflow. Mapping the natural-potential field so generated can map waterflow. A positive natural potential may indicate downward waterflow. A negative may indicate upward evaporation. Contour lines of increasing magnitude may indicate the direction of horizontal waterflow (Lange, 1993). Simultaneous vertical and horizontal resistivity monitoring has been used to trace an injected electrolye solution to confirm predicted flow paths and flow rates (Fish et al., 1987).

Tracing studies need to be carefully designed in diffuse flow regimes as traces of dyes can contaminate or invalidate future studies for several decades. Only dechlorinated water should be used both in diluting the dye and in "chasing" it if a dry site is used for injection. Charcoal packets placed throughout the cave can serve as passive detectors, providing a non-quantitative indicator of the areal extent of dye movement. Mammoth Cave has developed continuous flow, quantitative dye detectors.

Helium, fluorescein, rhodamine WT, Tinopal CBS-X (a fluorescent brightener), and lycopodium spores in that order probably have the least impact on caves especially if they are below 100 ppb. All mixing and calibration equipment should be separate from the area used to test for dyes. The lab must be checked with UV light after every use and kept clean. Incandescent lighting reduces photodegradation.

The sharpness of the drip rates and dissolved ion peaks is partly determined by permeability rates. Sharpness and short lived events can only be discerned by continuous measurement, such as with the use of dataloggers and tilt buckets. Because of great variation in individual drip rates, area coverage using plastic tarps can be used. They should be changed as needed to prevent scale buildup.

Paleoflow directions can be determined by pebble imbrication, bone orientation, scallop size and direction, etc.

Paleoflooding can be estimated from the extent and number of bevels, atmospheric corrosion rills, etc.

Concentration of flow from buildings and parking lots can excavate infilled caves and cause land subsidence. Associated changes in water quality (oil, grease, metals) can impact speleothem growth and cave biota.

The natural range of water tables, drainage basins, inputs, probable flow routes, and discharges should be established. Establishing water budgets can help in each basin in determining components of the water yield, the runoff from a drainage basin. Precipitation, known karstic flow, and now evapotranspiration can be directly measured or at least modeled so that interstitial leakage, unknown karstic flow, and/or residence times can be calculated. Aerial photographs can be studied to locate lineaments that might influence flow rates.

Human-caused changes in waterflow rates, timing, duration, and levels can cause subsidence, erosion, reduction of biotic habitat from siltation and relative humidity changes, reduced organic input from floods, etc. A combination of quantitative dye tracing with flood pulse water quality sampling can identify point and nonpoint pollution sources and discern their individual contribution to the overall contaminant load. As subsurface basin divides in karstic terrain typically do not correspond to surface divides, locating the divides is important in influencing local or regional land use.

Once the natural range and comparisons with more pristine caves/above surface areas has been determined, mitigation can begin. Prescribed fires, manual cutting of brush, or soil catchment devices above caves can restore waterflow amounts and timing lost as a result of fire suppression, forest conversions, soil erosion, etc. Any major mitigation effort needs to be monitored.

Flood pulses can be the primary flow mechanisms which transfer pesticides, coliform bacteria, suspended solids, and naturally occurring heavy metals. Except for the leaching of zinc from galvanized steel handrails in caves, heavy metal contamination usually is not a problem in caves and karst because of the buffering effect of carbonates. However, heavy metals can be absorbed onto organics or clay particles especially during times of high turbidity and contaminate stream sediments for decades (Martin & Coughtrey, 1982). Particulate matter can also transport organic contaminants as well. An increase in turbidity can predict an approaching flood pulse.

Chloride is an inexpensive test which may indicate the presence of oil field brines, road salts, urination, algae spraying, sweat on handrails, or other sources. Ratios of chloride to other ions such as potassium and sodium can help pinpoint the type of pollutant. For example, if high chlorides and sulphates are found without high bacterial counts then oil field brine contamination is suspected. A topical survey would then be initiated with expanded parameters such as bromide and additional sites temporarily added to identify the source(s). High sulphates and low chlorides may indicate natural dissolution of sulphate minerals if the mass flux is relatively constant, and high chlorides with low sulphates may indicate contamination by road salt or sweaty hands.

Nitrate-nitrogen values can be a useful predictor of human-caused eutrophication of water. A high nitrogen-nitrate concentration indicates a high nutrient load, which, depending on other parameters such as bacterial counts, may be from septic waste or fertilizer sources. Dissolved nitrogen should have priority in monitoring as it is more important than nitrogen-rich particulates both in biological uptake and reactivity with other ions. The same is true for most if not all limiting nutrients.

Fecal streptococci bacterial test results are used in ratio with fecal coliform to differentiate between human or animal pollution of the water. A fecal coliform/fecal streptococci ratio (FC/FS) of 4.0 or greater indicates pollution derived from human wastes, and a value of .7 or less indicates pollution from livestock or other animal wastes. A FC/FS between 2 and 4 suggests the predominance of human wastes in mixed pollution, and a ratio between .7 and 1.0 indicates primarily animals waste in mixed pollution (Olsen, 1993).

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Appendix A

OREGON CAVES INVENTORY, 1993: DEFINITION OF TERMS Rev. 8/20/93

Y/N, # or % occurs after each number
A: yes = 1 no = 0
# are individual instances or occurrences:
0 = none present
1 = exactly one time or occurrence (cluster of items, such as many soda straw are counted as one) if it occurs within a 3' radius
3 = several (two to nine) 9 = numerous (ten or more)

% - Percentage coverage (areal) 0 - none
10 - 1-10% of area designated in individual descriptions (such as only ceilings, floors, etc.)
30 - 11 to 30% 60 - 31 to 60% 90 - 61 to 100%
A gap of more than 1 foot between any item constitutes a gap in coverage or distribution

1. Station No.
All marked stations are to be inventoried up to halfway to all other stations, both vertically and horizontally. This involves finding such sequences in the cave before any inventory can be done. Obvious alcoves or side leads that can be entered by a person will have their own separate station. Make sure you read the stations correctly. Check both sides of the tag to eliminate ambiguity. Record the station number and letter exactly as they appear on the tag. All lower case letters should be recorded as lower case letters (only halfway up to next line) and all upper case letters should be recorded as upper case letters (all the way up to the next line). On the tour route, tags are brown painted and lack flagging to make them less conspicuous. Make sure the sequence of numbers is followed. If the station No. is incorrect, cross it out and add correct one beside the incorrect No. Don't erase & put a new number in the erased place.

2. Cave Zone (L(ower), M(iddle), G(host Room) (from the start of Miller's Chapel to Exit Tunnel end, S(outh Room). Be sure to mark this.

3. # Canopies - overhanging layers of flowstone which formed on sediment now washed away. Usually bits of silt, gravel, etc. can be seen underneath the canopy that were not washed away with the rest of the sediment. Make sure that it is layers of calcite and not a projection of chert, etc. of the wallrock. You will see many things that are not canopies in the cave but some canopies do occur. Keep looking. A canopy completely covering the floor is a

false floor. Note this on the back of the inventory form if this occurs.

4. # Cave Pearls - Rounded, loose concretions of calcite usually inside a driphole. They are very rare but do occur in the cave. If these appear to be hard moonmilk (granular surface), make note on back of inventory form.

5. # Columns - Both massive and straw.

6.# Conulites - Conical formations (like a ice cream cone) formed from mud impregnated by calcite from dripping water and un-calcified layers of mud being subsequently washed way by the dripping water.

7.% Superaqueous (above past or present water line) coralloids - Rough, globular, rounded or sharp. No crystals are visible. Does not occur below former or present water line. AZ-P (azimuth) is direction that populations of coralloids face if on one side of a formation, etc.

8.% Subaqueous (below past or present water line) Coralloid - Rough, globular, rounded or sharp. No crystals are visible. Occur below former or present water line.

9. Coralloid Stem AZM (azimuth) is direction that individual stems are pointed towards. Add comment on back of form if individual stems of coralloids point upward or downward.

10. Coralloid Patch AZM (Azimuth) is direction that populations of coralloids face if on one side of a formation, etc.

11.# Dams, Rimstone - Parallel and/or convoluted ridges are greater than 1/2" high. Usually on floors.

12% Dams, Microgours - Parallel and/or convoluted ridges are less than 1/2" high. Usually on walls.

13.# Drapery - Linear feature on walls and ceiling, web-like attachment to stalactite, etc. Includes bacon rind (color banding).

14. % Flstn (Flowstone) - Deposited calcite in the form of hard coatings or cascades.

15. % Flstn, exfoliated - Onion like layers underneath revealed

16. # Flstn, White - White flowstone, excludes creamy colors

17. % Flstn, Incised - Dendritic or rills from flowing water re-solution.

18. % Flstn, Pitted - Small pits in flowstone.

19. Flstn, Pitting AZM (azmuth is direction that pitted surface faces. Such differential solution is caused by atmospheric corrosion.

20. % Flstn, Upslope AZM (Azimuth) - Bearing is in direction from which flowstone is coming from

21.% Moonmilk, Soft - White, like creamy cottage cheese when wet, like dried milk when dry

22.% Moonmilk, hard - Distinct more or less vertical color change with adjacent wall or flowstone. Fluting (vertical grooves) may be present

23.% Shelfstone - Horizontal flowstone layers surrounding past or present pools. May have broken soda straws between layers

24.# Soda Straws - Vertical formations with the diameter of a water droplet. Looks like a soda straw, often with a hollow center.

25.# Broken Formations, loose

26.# Broken Formations, cemntd (cemented) - cannot be picked up. Only the outline of the formation may be seen.

27.# Stalactites - Vertical formations with a diameter greater than that of a water droplet.

28.# Stalagmites - Vertical formations rise from a floor or she lf.

29.# Crystal-lined Pool - Visible crystals, usually in pools or former pools as evidenced by crystals below horizontal line.

30.% - Super-aqueous Xstal - Visible crystals, usually in small pockets in walls

31.# Helictites - Anything growing out of odd angles from dripstone. Anything tubular growing out of walls.

Tour Artifacts

32.A Construction Rubble - Loose rock of which more than 40% looks freshly broken, especially marble. Rocks that have been stacked are construction rubble.

33.A - Tour Trail Miscell - Includes Lights (Artificial lights used by trail), stairs, cables, wires, conduits, and trail

Speleogens:

34.# Arches - Natural bridges. Must be less than 6 feet wide

35.# Bevel - Horizontal notches in walls more than three inches high. It should exist everywhere or most places in a room unless covered by speleothems. Caused by flooding and stagnation of water level for weeks or months.

36.# Boxwork - non-joint - Converging, diverging or intersecting lines of usually light colored calcite (argillite less often) that stand out from walls or ceiling.

37. Boxwork - Joint - Parallel lines of usually light colored calcite (argillite less often) that stand out from walls or ceiling.

38.% Corrosion - Wallrock comes off with fingernail scratching

39.# Dome pits, fluted - Vertical and rounded indents in ceiling. Length is less than 3 times width. Either length or length is at least six inches. Fluting (incised rills) and/or much flowstone is present. Top may extend out of sight.

40.# Dome pits - Smooth - No fluting or not much flowstone present

41.# Hoodoos - Hoodoos are vertical piles of uncemented material (silt, clay) protected from dripping water by gravel, etc.

42.# Meanders - Curving notches in the floor of cave

43.# Pendants/Anastomoses. Pendants are vertical sections of wall rock often surrounded by anastomoses. Vertical section is at least three times longer either length or width of projection

44.# Pillars - Vertical sections of rock connecting floor and ceiling and less than six feet across

45.# Potholes - Round indentations in flowstone or bedrock floor of cave. Does not include holes in trail or holes in loose sediment. Frequently have rounded stones inside.

46.# Rills - Joint - Narrow notches (up to a few inches across) in walls and floor. Coverage if for walls and floor only. Parallel rills are joint controlled (compare with boxwork).

47.# Rills - Non-Joint - Converging or diverging rills are not joint controlled

48.% Scallops - Scallops are asymmetrical cusps usually in walls or ceilings.

49. Scallops, Azimuth. Percent of walls and ceiling only. The steep side of each cusp points upstream and azimuth points upstream.

49. Airflow Azimuth - Compass direction in which air is coming from (looking upstream

50. A - X-Section, Breakdown (angular rock more than 10 cm.)

51. A - X-Section, Canyon - A vertical slot

52. A - X-Section, Manmade. Fresh-looking broken rock or vertical sediments in place on floor, generally by trail and old trail, sometimes off-trail

53. A - X-Sectn, Tubular - Tubular Cross-section of passage

54. % Clay film - clay can be rubbed off by brushing surface with shirt

55. % Clay Worm, Complex - At least two sharp angles to worms. % coverage on walls and ceiling

56. % Clay Worm, Long - More than three times longer than broad

57. % Clay worms, Round - Less than three times longer than broad

58. % Clay Worm, Hard - Clay worms cannot be smeared with finger

59. % Fill, Clay - Clay smears, does not feel gritty

60. % Fill, Silt - Dirt feels gritty

61. % Fill, Gravel - Mostly particles greater than .5 cm

62. % Fill, Breakdown - Angular rock fragments more than 10 cm.

63. % Fill, Flowstone - Smooth layers of limestone, usually extension of flowstone coming down walls. Note on back of inventory form if false floors exist where flowstone covered the entire floor of sediments and the sediments have been washed out.

64. % Fill, Cemented Clastic. Fill cannot be pulled apart with fingers

65. A Fill-Differentiated. Alternating layers of larger and smaller particles. Gravel is often rounded.

66. Fill, Upstream, AZM (Azimuth) Direction of azimuth points against angle of flat pebbles (like shingles on a roof)Give horizontal bearing facing upstream (against lean of elongated pebbles)

Geological:

67. # Dikes, breccia - Percent of rock fragments greater than .5 cm is 50% or more

68. # Dikes, quartz - Percent of quartz diorite (salt and pepper rock) is more than 50% or more

69. A Fault Offset - The distance that marker beds, banding or layers have been separated.

70. Fault Dip _____ - Dip is the angle from the horizontal.

71. Fault Strike ______ - Strike is the orientation of line caused by intersecting a horizontal plane with the plane of the fault

72. # Interbeds-ash/argillite - Black layers. Argillite is hard and cannot be scratched with knife, marble can. Ash can be smeared with fingers.

73. # Interbeds-chert - Chert is generally grey (sometimes with black stains), is blocky and angular and sticks out from the marble walls. Often highly fractured.

74. # Jointing - Parallel cracks with no sign of offset of chert layers on either side of crack

Environment:
75. A Air, Smoke moves
76. A Air, Feel on face
77. A Air, Flame wavers
78. A Air, Flame goes out

79. A Drip--Slow - Spacing of some drips is more than 3 seconds.

80. A Drip--Fast - Spacing of some drips is less than 3 seconds.

81. A Moist - Causes noticeable darker stain on cloth

82. Pooled Water - Water drips from finger placed in pool.

83. Y/N - Stream - Flowing water

84. Passage Ht (height) in feet, averaged

Biota:
85. # Bats

86. # Bug Sites - All areas where macro-invertebrates have been seen. Give number for traps, horizontal distance, and azimuth from survey point to trap on comments side of inventory form

87. # Cave Slime - Small white, fairly circular dots. Sometimes concentric bands of color, kind of like lichens. Does not flake off like moonmilk.

88. # Rodent Trails - Includes dark patina (sometimes has glossy look) where rodents have traveled and left trails as well as rat droppings. Be careful that the vertical staining is not from root sap, etc.

89. # Bones, free

90. # Bones, Buried

91. A Snail Shells

Archeology
92. # Arrows

93. # Artifacts

94. # Writing

Vandalism:

95. # Breakage - Abrupt fairly horizontal terminations of stalactites, draperies, etc. Includes loose soda straws on floor.

96. A Healing. For 1 (Yes), healing must be measurable.

97. # Healing Length (average length of soda straws actually showing regrowth).

98. # Potential for further damage from vandalism (areas within reach of six foot tall person)

99. # Trash (too much to pick up during inventory process)

Note: Once the inventory is completed, check to make sure all blanks have been filled in. Circle the cave zone. Put flagging on tag to unsure that the station is not inventoried again.