



A Protocol on Sampling Designs and Methodologies for Selective and Adaptive Monitoring in Caves of Air Temperature, Relative Humidity, and Cross-Sectional Air Velocity throughout the Cumberland Piedmont Network

Natural Resource Report NPS/CUPN/NRR—2012/491



ON THE COVER

CUPN's instrument lift system is shown installed in Marion Avenue (in Mammoth Cave). The instrument lift system is capable of automatedly raising and lowering meteorological instrumentation along its height. This capability allows collection of meteorological data at those heights and should lead to a greater understanding of cave meteorological processes. This protocol's second author is shown servicing the unit.

Photograph by: Kurt Helf

A Protocol on Sampling Designs and Methodologies for Selective and Adaptive Monitoring in Caves of Air Temperature, Relative Humidity, and Cross-Sectional Air Velocity throughout the Cumberland Piedmont Network

Natural Resource Report NPS/CUPN/NRR—2012/491

Dr. Robert L. Woodman
National Park Service - Gulf Coast Network
635 Cajundome Blvd.
Abdalla Hall, Suite 124
Univ. Louisiana-Lafayette
Lafayette, LA 70506

Johnathan W. Jernigan
National Park Service - Cumberland Piedmont Network
National Park Service Air Resources Division
Mammoth Cave National Park Service
P.O. Box 7
Mammoth Cave, KY 42259

Bobby C. Carson
National Park Service
Mammoth Cave National Park
P.O. Box 7
Mammoth Cave, KY 42259

Bill J. Moore
National Park Service – Cumberland Piedmont Network
Mammoth Cave National Park
P.O. Box 8
Mammoth Cave, KY 42259

February 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Cumberland Piedmont Network's intranet site (<http://www1.nrintra.nps.gov/im/units/cupn/>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>).

Please cite this publication as:

Woodman, R. L., J. W. Jernigan, B. C. Carson and B. J. Moore. 2011. A protocol on sampling designs and methodologies for selective and adaptive monitoring in caves of air temperature, relative humidity, and cross-sectional air velocity throughout the Cumberland Piedmont Network. Natural Resource Report NPS/CUPN/NRR—2012/491. National Park Service, Fort Collins, Colorado.

Contents

	Page
Contents	iii
Figures.....	ix
Tables.....	xii
Appendixes	xii
Abstract.....	xiv
Acknowledgments.....	xiv
Background and Objectives	1
Issues Being Addressed and Rationale for Cave Meteorology Monitoring	2
Historical Development of Cave Meteorology Monitoring at MACA.....	8
Measurable Objectives.....	14
Sampling Design.....	16
The Sampling Designs	16
Rationale for Selecting these Sampling Designs over Others	18
Site Selection	19
Sample Frequency and Replication	19
Field Methods	20
Field Season Preparations, Field Schedule, Site-Check, and Equipment Setup.....	20
Sampling Methods – Dataloggers and Sensors Used to Collect Atmospheric Data	20
Sampling Methods.....	23
Air temperature and relative humidity spatial sampling events.....	24
Air temperature and relative humidity temporal sampling by a HOBO	25
Air velocity sampling: seasonal mode	26
Air velocity sampling: monitoring mode.....	27

Contents (continued)

	Page
Data Management	28
Overview of Database Design	28
Data Entry	29
Data Verification and Validation	29
Data Archival Procedures	29
Analysis and Reporting	32
Data Analysis	32
Reporting	32
Personnel Requirements and Training	34
Roles and Responsibilities	34
Qualifications and Training	34
Operational Requirements	36
Field Schedule and Annual Workload	36
Facility and Equipment Needs	37
Startup and Monitoring Costs	37
Equipment List for Air Temperature / Relative Humidity and Air Velocity Sampling	38
Equipment List for Air Temperature / Relative Humidity Sampling	38
Equipment List for Air Velocity Sampling	39
Procedure for Revising the Protocol and Archiving Previous Protocol Versions	40
References	42
Standard Operating Procedure (SOP) # 1: Training of Field Personnel	44
Checklist 1 – Generalized Logistical Checklist for Cave Meteorology Monitoring	45

Contents (continued)

	Page
Standard Operating Procedure (SOP) # 2: Pre-Sampling	46
General Preparation and Review	46
Campbell CR10X dataloggers: wiring and programming instructions	47
Campbell Datalogger Wiring: Air Temperature and Relative Humidity.....	47
Campbell Datalogger Wiring: Air Velocity.....	47
Changing the SDI-12 Address of a Windsonic Ultrasonic Wind Sensor	49
Campbell Datalogger Programs: Transfer from a PC to the Datalogger	51
Launching HOBO Dataloggers.....	61
Accessibility Check of Sampling Caves.....	62
Scheduling Field Work	63
Organizing Supplies and Equipment	63
Checklist 2 – Generalized Logistical Checklist for Cave Meteorology Monitoring	64
Checklist 3 - Air Temperature and Relative Humidity Seasonal Sampling Supplies/Equipment	65
Checklist 4 – Air Velocity Sampling Supplies/Equipment.....	66
Standard Operating Procedure (SOP) # 3: Establishment and Location of Sampling Sites.....	68
Establishment of Sampling Sites	68
Sampling Space Criteria for Air Temperature/Relative Humidity:	68
Sampling Space Criteria for Air Velocity Sampling:	69
Location of Sampling Sites during a Sampling Session.....	69
Standard Operating Procedure (SOP) # 4a: Seasonal Sampling and Monitoring of Air Temperature and Relative Humidity.....	72
Sampling of Cave Air Temperature and Relative Humidity along a Cave Surface	72

Contents (continued)

	Page
Overview of “Seasonal” Spatial Sampling	73
Detailed description of “Seasonal” Spatial Sampling.....	73
Campbell Scientific Datalogger Modes and Commands.....	82
Flags	84
Overview of “Continuous” Sampling.....	85
Offloading Data from a HOBO datalogger.....	85
Offloading Data from a HOBO datalogger and replacing the datalogger’s battery	86
Standard Operating Procedure (SOP) # 4b: Seasonal Sampling and Monitoring of Cross-Sectional Air Velocity	88
Seasonal Sampling of Cave Air Velocity	88
Equipment Installation	89
Equipment Removal.....	91
Interim Equipment Maintenance.....	94
Campbell Scientific Datalogger Modes and Commands:.....	95
Flags	98
Standard Operating Procedure (SOP) # 5: Post-Sampling	100
Procedures.....	100
Campbell Scientific’s Storage Module Offload Procedure:	101
Onset’s HOBO Shuttle Offload Procedure.....	102
Post-Trip Logistical Checklist	103
Standard Operating Procedure (SOP) # 6: Data Management.....	104
Introduction.....	104
Purpose.....	104

Contents (continued)

	Page
Expected Audience	104
Cave Meteorology Database - Metadata.....	105
Cave Meteorology Database.....	105
Cave Meteorology Data Model.....	106
Database Structure	106
Data Flow and Data Entry	108
Data Flow.....	108
Data Entry	108
Data Verification	110
Data Validation.....	111
Database Administration	111
Data Maintenance	111
Data Organization.....	111
Data Security and Integrity	112
Version Control.....	112
Data Logs and Backups	113
Data Availability.....	113
Literature Cited.....	113
Appendix A: Data Stewardship Roles for Cave Meteorology Monitoring at Mammoth Cave National Park	114
Appendix B: Table and Field Descriptions – Cave Meteorology DB (v1.0)	116
Appendix C: QA/QC Process Flow for Cave Meteorology Monitoring (<i>In Development</i>).....	124

Contents (continued)

	Page
Standard Operating Procedure (SOP) # 7a: Analysis of Air Temperature and Relative Humidity Data.....	126
Data Flow.....	127
Data Analysis.....	128
Standard Operating Procedure (SOP) # 7b: Analysis of Cross-Sectional Air Velocity Data.....	130
Data Flow.....	130
Data Analysis.....	131
Standard Operating Procedure (SOP) # 8: Reporting.....	134
Report Format.....	134
General.....	134
Tables.....	135
Figures.....	135
Pictures.....	135
Report Outline.....	135
Review Procedure.....	136
Internal Review.....	136
Park Review.....	136
External Review.....	137
Distribution Procedure.....	137
Identifying Stakeholders.....	137
Distributing Reports.....	137
Literature Cited.....	138
Standard Operating Procedure (SOP) # 9: Revising the Protocol.....	140
Procedures.....	140

Figures

Page

Figure 1. Current gate/Plexiglas configuration at the Historic Entrance to Mammoth Cave. For the previous configuration, there was no Plexiglas paneling in place. In the winter, surface air was free to pour into that part of the cave unabated.	2
Figure 2. Left image: a cluster of cave crickets on the ceiling in a MACA cave. NPS photo by CUPN staff. Right image: a close-up of a cave cricket. NPS photo by Kurt Helf.	3
Figure 3. Blockhouse at the Frozen Niagara Entrance to Mammoth Cave. Note the airtight, rotating door in the rightmost image that prevents air from pouring in while the outer door is open but still permits visitors to pass.	3
Figure 4. Left image: Moisture-related damage to a cane reed torch fragment from MACA. NPS photo by Rick Olson. Right image: Saltpeter leaching vats in the Historic Section of Mammoth Cave. Note moisture (circled in red) on the vat in the foreground. NPS photo by Kurt Helf.	4
Figure 5. Radon time series from weekly grab sampling in the entrance passage to the Historic Section of Mammoth Cave. Note that radon is highest in the summer and lowest in the winter.	5
Figure 6. Carbon dioxide data from three sites in the Mammoth Cave System and one on the surface (“Air Quality Station”). Note that, generally, the Wright’s Rotunda site has lower concentrations than the other two cave sites. Wright’s Rotunda has fewer visitors than either of the other cave sites.	6
Figure 7. Formation in a MACA cave. Photo by David S. Carson.	6
Figure 8. Left graph: The effect of the Historic Entrance gate modification on cave air temperature. Right graph: The effect of the same on cave air velocity (shown equivalently in the graph as “air flux”).	8
Figure 9. A first attempt at a cross-sectional airflow sampling design. Data were collected instantaneously from a cross-section in the Historic Entrance to Mammoth Cave. Dots represent air velocity data collected. The surface is an interpolated best fit surface for the set of velocity data.	9
Figure 10. Three airflow sampling periods in 2005 (from left to right, January 19 through February 4, March 25 through April 4, and June 20 through 30) suggesting that (1) airflow data are too noisy for our initial grab sampling approach, and (2) airflow across this particular cross-section covaries temporally.	10

Figure 11. Typical spatial air temperature and relative humidity seasonal sampling data.....	11
Figure 12. Air temperature and relative humidity data collected by three HOBO dataloggers in the same cave room within the Mammoth Cave system. Each datalogger was at a different location within the cave room. Note that that all of the air temperature data streams and relative humidity data streams co-vary.	12
Figure 13. Covariance of air temperature and relative humidity in the Corkscrew and Rotunda. Both sites are in the Historic Section of Mammoth Cave. The red lines are lines of best fit. The r-squared values for the Corkscrew data and the Rotunda data are 73% and 87%, respectively, indicating good correlation between the two parameters.	13
Figure 14. Several years of air temperature and relative humidity data from a site in the Historic Section of Mammoth Cave.....	14
Figure 15. Campbell Scientific’s CR10X Datalogger for Measurement and Control. Image downloaded from www.campbellsci.com	21
Figure 16. Onset Computer Corporation’s HOBO Pro RH/Temp Datalogger. Image downloaded from www.onsetcomp.com	22
Figure 17. Vaisala’s HMP45C Temperature and RH Probe. Image downloaded from www.campbellsci.com	23
Figure 18. WINDSONIC-L 2-D Sonic Wind Sensor. Image downloaded from www.campbellsci.com	23
Figure 19. Typical at/rh sampling grid.....	24
Figure 20. Relationships Diagram for the Campbell Portion of the Cave Meteorology Monitoring Protocol.....	106
Figure 18. Relationships Diagram for the Air Flow Portion of the Cave Meteorology Monitoring Protocol.....	107
Figure 22. Relationships Diagram for the HOBO Portion of the Cave Meteorology Monitoring Protocol.....	107
Figure 23. Data Entry Form for the Campbell Portion of the Cave Meteorology Monitoring Protocol.....	109
Figure 19. Data Entry Form for the Airflow Portion of the Cave Meteorology Monitoring Protocol.....	109
Figure 20. Data Entry Form for the HOBO Portion of the Cave Meteorology Monitoring Protocol.....	110

Figure 21. CUPN Project Directory Structure	112
--	------------

Tables

	Page
Table 1. Sampling methods/designs and their applications.	1
Table 2. Detection limits with our selected instrumentation.....	22
Table 3. Example schedule for air velocity sampling.	36
Table 4. Annual workload estimates for at/rh and air velocity sampling.	37

Appendixes

	Page
Appendix A: Air Temperature/Relative Humidity Seasonal Sampling – Field Operations Notes.....	142
Appendix B: Air Temperature and Relative Humidity – Event Data.....	144
Appendix C: HOBO Pro RH/Temp Datalogger – Site Setup and Maintenance Field Observer Form	146
Appendix D: Cross-Sectional Airflow - Field Operations Notes	148
Appendix E: Cave Cross-sectional Airflow – Site Maintenance Field Observer Form	152
Appendix F: Cave Cross-sectional Airflow – Seasonal Equipment Setup or Disassembly Field Observer Form.....	154
Appendix G: NPS/WKU Engineering Instrumentation Lift Project System Installation and Operation Procedures	156

Abstract

The cave atmosphere is influential upon many cave resources. Many animals, for example, often need air temperature to be within a specific range in order to flourish or even survive. Wooden cultural artifacts are also in need of appropriate atmospheric conditions. A moist, high-humidity environment can cause mold and mildew to grow on such artifacts and ultimately result in their biodegradation. Since this is the case, it is important that cave atmospheric parameters remain within desired bounds. In most caves, keeping air temperature and relative humidity within their desired limits means that air velocity must be manipulated (frequently by blocking or enlarging cave entrances to modify ventilation from the outdoors). Therefore, sampling designs and methodologies are provided for monitoring air temperature, relative humidity and air velocity in cave systems. A list of sampling sites is not provided. Instead, the sampling designs and methodologies are generic and can be applied to many situations. The data collected may support management in determining courses of action that will either maintain atmospheric conditions in their present state or alter them in some desired way. The data may also be used simply to establish baseline conditions in caves.

Acknowledgments

The investigators wish to thank Maggie Mahan, Chris DeWildt, Douglas Foster and Katie O'Neil for their assistance with data collection. Without their assistance, this protocol would not have been possible. Also, thanks to the folks in Mammoth Cave National Park's Division of Science and Resources Management who took to time to provide comments on the draft version of this protocol. The protocol is much improved thanks to their comments.

Background and Objectives

The protocol provides sampling designs and methodologies for assessing cave environmental parameters in the contexts of supporting long-term cave system monitoring, providing management-directed assessment of local and site-specific conditions. The protocol also provides environmental conditional assessment in support of biotic sampling and monitoring being performed in caves as addressed by other Cumberland Piedmont Network (CUPN) monitoring protocols. The particular parameters addressed by this protocol are cave air temperature, relative humidity, and cross-sectional airflow. In contrast to most monitoring protocols, which define particular sites and associated sampling designs and schedules, this protocol provides examples and general guidelines for possible sampling designs and applications of described techniques. These generalized sampling designs, along with associated sample sizes and sampling frequency and temporal distribution, are intended to be adapted to meet specific user needs on a site-by-site and per-case basis. The methodologies and proposed designs provided in this protocol are expected to be fully usable in a wide variety of cave system configurations and sizes, and hence may be readily adopted by most cave resource managers with little or no detail modification. The methodological SOP's are constructed to be fully independent and "stand-alone," and each described methodology may be separately implemented in any appropriate situation, provided that appropriate equipment and personnel are available. The methodological SOP's provide instructions on how to:

1. Measure air temperature and relative humidity spatially (spatial at/rh) within a cave space along a cave surface (ceiling, floor, or wall).
2. Measure air temperature and relative humidity temporally (temporal at/rh) using datalogging systems at one point within a cave space.
3. Simultaneously measure airflow spatially and temporally (spatial/temporal airflow) using datalogging systems within a cave cross-section.

Table 1. Sampling methods/designs and their applications.

<i>If you want to:</i>	<i>Use this sampling method/design:</i>
Assess the air temperature and relative humidity under which cave invertebrates dwell. <i>Using the relative humidity sensors that we suggest, this only works really well in areas with relative humidity less than 90 percent.</i>	Spatial at/rh
Assess the air temperature and relative humidity under which bats dwell. <i>Using the relative humidity sensors that we suggest, this only works really well in areas with relative humidity less than 90 percent.</i>	Spatial at/rh and/or temporal at/rh
Gauge how well a cave is ventilated.	Spatial/temporal airflow
Assess the impact of changes in cave gating on cave airflow.	Spatial/temporal airflow
Assess the impact of changes in cave gating on air temperature and relative humidity along some cave surface. <i>Using the relative humidity sensors that we suggest, this only works really well in areas with relative humidity less than 90 percent.</i>	Spatial at/rh and/or temporal at/rh
Determine the relative humidity of air masses around wooden artifacts and likelihood that atmospheric conditions are conducive to biodegradation of these artifacts. <i>Using the relative humidity sensors that we suggest, this only works really well in areas with relative humidity less than 90 percent.</i>	Spatial at/rh and/or temporal at/rh and/or spatial/temporal airflow

While these methods were developed with the caves at Mammoth Cave NP (MACA) as their target, they may be applied at other caves as well. Table 1 shows examples of typical applications of these sampling designs.

The scope of the protocol is to provide tools to management for the assessment of large-scale impacts to cave air temperature, relative humidity, and airflow. We have chosen to address “large-scale” changes in these parameters for two reasons. First, the thermal dynamics of most cave systems are not known in great detail and are extremely complex, so that management actions can not be reliably prescribed to affect small-scale changes at any given site. Second, instrumentation to measure the targeted cave meteorological parameters with high accuracy and resolution is expensive and difficult to maintain. A table in a subsequent section “Sampling Methods – Dataloggers and Sensors Used to Collect Atmospheric Data” lists the detectability limits that we set and the accuracies of the instruments we propose to use. It should be noted that, should greater accuracy be desired for a particular application, more accurate instrumentation is available and may be substituted for our proposed instrumentation.

Issues Being Addressed and Rationale for Cave Meteorology Monitoring

Air temperature, relative humidity, and airflow are influential atmospheric parameters in cave systems and are relatively easy to impact through management actions (such as changes to cave gates, blockhouses, and heat from lighting fixtures). For example, if management were to change the size of a cave’s entrance by installing new doors that have different shapes or different coverage (as shown in figures 1 and 3), then significant impacts on the cave climate could result. Specifically, the action could produce changes to the air temperature and relative humidity (at/rh) within the cave’s variable temperature zone as well as the variable temperature zone’s extent into the cave. Such changes to atmospheric parameters can impact a cave’s biotic/abiotic components and geochemical processes. So, monitoring the status and trends in air temperature, relative humidity and airflow in caves of interest is a useful warning metric for impacts upon cave components and geochemical processes.



Figure 1. Current gate/Plexiglas configuration at the Historic Entrance to Mammoth Cave. For the previous configuration, there was no Plexiglas paneling in place. In the winter, surface air was free to pour into that part of the cave unabated.

Air temperature, relative humidity and airflow all comprise important environmental properties affecting both key species and biological communities in cave ecosystems. Bats, for example, require air temperatures in their hibernacula to be cold enough to lower their metabolism. A lower metabolism results in bats using less of their fat stores and prolonging the period over which they can survive without food. The endangered Indiana bat (*Myotis sodalis*), for example, has an optimal hibernation temperature range of 3 – 6 degrees Celsius (Indiana Bat Recovery Team 1999). In the Historic Section of Mammoth Cave, various gate configurations, such as that shown in Figure 1, have resulted in unnatural atmospheric conditions that may have contributed to the current absence of significant populations of bats (Olson 1996 and Jernigan 1997).



Figure 2. Left image: a cluster of cave crickets on the ceiling in a MACA cave. NPS photo by CUPN staff. Right image: a close-up of a cave cricket. NPS photo by Kurt Helf.

Crickets, on the other hand, display a striking tendency to “clump” in quasi-temporally stable locations along cave surfaces (Figure 2). This aggregative phenomenon is important since it determines the spatial distribution of guano fields in cave rooms, and these guano fields support guano-dependent communities of organisms. An understanding of the drivers for the spatial distribution of cricket aggregations would allow cave managers to determine what impacts a management action may have upon that distribution. While drivers of cave cricket aggregation are unknown, some possible drivers posited amongst the authors and CUPN staff includes the spatial distribution of air temperature, relative humidity, and airflow.



Figure 3. Blockhouse at the Frozen Niagara Entrance to Mammoth Cave. Note the airtight, rotating door in the rightmost image that prevents air from pouring in while the outer door is open but still permits visitors to pass.

Cultural artifacts in caves are also dependent upon “favorable” meteorological conditions, especially relative humidity. High-humidity and condensing environments are destructive environments for some artifacts (such as cane reed torch fragments and saltpeter leaching vats shown in Figure 4) frequently seen in caves such as Mammoth Cave. An understanding of the meteorology around these resources (in both non-condensing and condensing environments) may lead to an enhanced understanding of how to control condensation in cave passages/rooms where management deems it unwanted.



Figure 4. Left image: Moisture-related damage to a cane reed torch fragment from MACA. NPS photo by Rick Olson. Right image: Saltpeter leaching vats in the Historic Section of Mammoth Cave. Note moisture (circled in red) on the vat in the foreground. NPS photo by Kurt Helf.

For many caves within the CUPN, the spatial distribution of air temperature within the cave system is a likely driver of the spatial airflow patterns within that system. This phenomenon is certainly the cause of air movement in Historic Mammoth Cave (Jernigan 1997). That is, differences in temperatures between neighboring air masses cause air movement amongst those masses. This type of air movement is a method of heat transfer known as convection (hot air rises and cold air sinks). In Historic Mammoth Cave, this same process also drives exchange between the cave air and air on the surface, thereby serving as a mechanism for the infiltration of air from the outdoors into the cave system (Jernigan 1997). These air movements and the resultant supply of surface air may result in the following:

- Replacement of cave air with surface air that is relatively free of trace gases that might otherwise build up in the cave system.
- Impacts to cave formations through the physical movement of air.
- Exchange of thermal energy between the cave system and the surface.
- Changes in the amount of heat energy contained within cave surfaces.

There are a couple of trace gases of particular interest in caves, one such gas being radon. Radon is a radioactive substance produced through the decay of uranium which is commonly found in cave rock and soils. When radon decays, alpha radiation (called radon daughters) is released into the surrounding air and inhaled by human visitors, damaging their lung tissue. Thorium is also common in cave rock and soil and it also produces alpha radiation (called thoron daughters).

Total alpha radiation within a cave is found by adding its radon and thoron daughter concentrations. In caves with radon levels high enough to be of concern to visitors, the total alpha radiation tends to be primarily radon daughters. So, rather than measure total alpha radiation, only radon gas is measured and that measurement is converted to an exposure index. While episodic, low exposure to alpha radiation has little effect on humans, chronic exposure (as experienced by tour guides) may damage the lungs and increase the risk of lung cancer (Aley et al 2005).

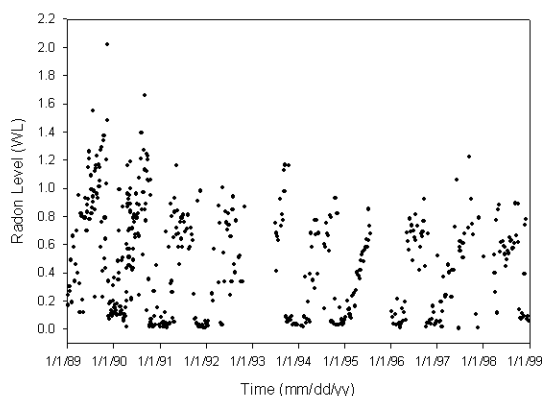


Figure 5. Radon time series from weekly grab sampling in the entrance passage to the Historic Section of Mammoth Cave. Note that radon is highest in the summer and lowest in the winter.

Sufficient airflow from the surface helps to minimize a cave's radon levels and an employee's exposure. Figure 5 shows data collected near the entrance to Mammoth Cave. Notice the low working levels during the winter and the relatively high working levels during the summer. At that entrance, air is incast during the winter so winter values are from air that is essentially outdoor air. Summer values, in contrast, are from cave air since during that time of the year airflow is outcast. For more information on radon monitoring at MACA, see Carson (1981), Jernigan (1999), Jernigan (2002) and Smith et al (1997).

A second trace gas impacted by airflow is carbon dioxide. Data from three sites in the Mammoth Cave System and one site on the surface at MACA are shown in Figure 6. Carbon dioxide occurs naturally in cave systems and is exhaled by visitors, and, while a small amount of the gas is harmless to cave systems, significant amounts of the substance may impact speleothem formation. Most speleothems (an example is shown in Figure 7) are formed when water that contains calcium carbonate is freed of its carbon dioxide and the calcite (CaCO_3) is able to precipitate out of solution and create a formation (<http://www.nps.gov/wica/naturescience/cave-formations-speleothems.htm>). If the cave atmosphere already has above a certain amount of carbon dioxide, then the "outgasing" of carbon dioxide from the water may not take place and little or no calcium carbonate will be deposited. To put it succinctly, high cave atmospheric levels of carbon dioxide are suspected to slow speleothem formation.

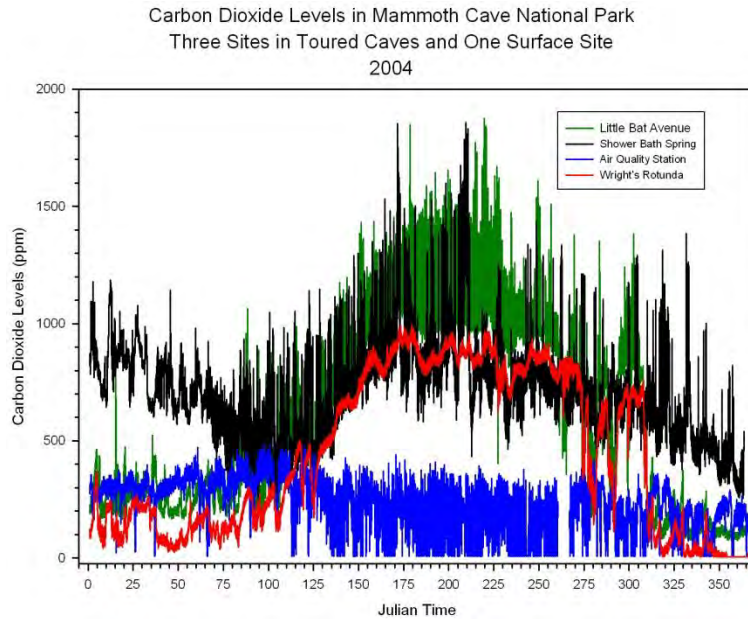


Figure 6. Carbon dioxide data from three sites in the Mammoth Cave System and one on the surface (“Air Quality Station”). Note that, generally, the Wright’s Rotunda site has lower concentrations than the other two cave sites. Wright’s Rotunda has fewer visitors than either of the other cave sites.



Figure 7. Formation in a MACA cave. Photo by David S. Carson.

Airflow into/out of caves with multiple entrances is generally caused by temperature differentials between cave air and outdoor air. When air moves into these cave systems from the surface, it brings its thermal energy. If the infiltrating air is relatively cold, then that air will cool the cave as it moves through until the infiltrating air has absorbed enough heat from the cave’s air and its surfaces. When these three entities are of the same temperature, air movement would cease and

the system would be in equilibrium. When the infiltrating air is relatively warm, the process reverses with the infiltrating air cooling to the temperature of the cave air and walls. The resultant distribution of thermal energy has impacts upon biotic and abiotic cave components (as discussed in the opening paragraphs in this section).

Changing the temperature of cave surfaces can have significant impacts upon the stability of these surfaces, potentially destabilizing the surface and producing rockfalls. For example, at MACA, a very cold air mass entering Mammoth Cave may have precipitated an extreme rockfall event (Olson 1995 and Jernigan 1997). This rockfall was posited to result from one of two processes: (1) contraction of the soon-to-be falling and surrounding rock (most substances contract when they are cooled) thereby decreasing the adhesive friction forces between the rock surfaces or (2) ice formation between the soon-to-be falling and surrounding rock. At MACA, during an unusually cold period on January 18, 1994, a low outdoor temperature of -16 °F was reached. The extreme differential between the air temperature in the cave and the air temperature outside the cave resulted in a large influx of cold air down Houchins' Narrows and into the Rotunda room. Through one of the two processes above, a 40 ton slab of rock became dislodged from the ceiling and crashed to the floor damaging saltpeter mining artifacts and a handrail. Other smaller and less significant rockfalls have also been observed.

For all of these reasons, sampling designs and methodologies for the collection of air temperature, relative humidity, and air velocity are presented. Through appropriate sampling designs and methodologies, management may determine what effects to the cave environment may have occurred as a result of their actions. Also, when the data are used to generate mathematical models, management may be able to prescribe actions that will produce target conditions where those conditions do not exist (as is the case with wooden War of 1812 saltpeter leaching vats in the Historic Section of MACA, where condensation is causing decay of these artifacts). Further still, the approaches presented (particularly for air temperature and relative humidity sampling) are also designed for use with other monitoring protocols that have been developed or are currently in development (i.e. cave cricket and cave beetle monitoring).

Monitoring of cross-sectional airflow provides an additional indicator of management impact upon the cave environment that measurement of air temperature and relative humidity can not. For example, the main gate at the Historic Entrance to Mammoth Cave was fitted with Plexiglas panels in 1996 (as shown in Figure 1) (Fry and Jernigan 2007). Air temperature data were collected within a few hundred meters of the entrance in a passage that channels the air exchanged between the cave and the surface. The entrance retrofit had no apparent impact upon air temperature at the data collection location. However, air velocity data were also collected at the location, and the entrance modification's impact on air velocity was significant. During winter, the entrance modification reduced air velocity by about fifty percent. So, had air temperature been the only parameter measured at that location, the impact would have gone undetected. Plots of these data are shown in Figure 8.

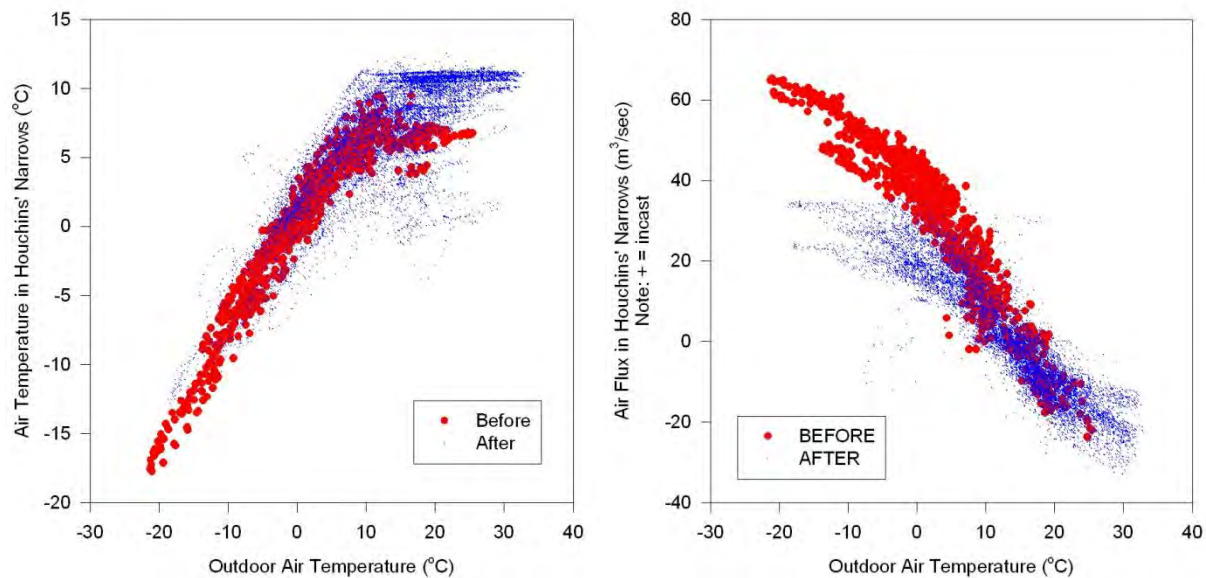


Figure 8. Left graph: The effect of the Historic Entrance gate modification on cave air temperature. Right graph: The effect of the same on cave air velocity (shown equivalently in the graph as “air flux”).

Historical Development of Cave Meteorology Monitoring at MACA

Recognizing the impacts that cave air quality has upon cave communities, long-term monitoring of cave meteorology at MACA was put forth as a component in a 1993 monitoring proposal. The proposal resulted in MACA being selected as a prototype monitoring park for the cave/karst biome (A Proposal 1993).

Extensive cave atmospheric data collection has been occurring at Mammoth Cave National Park (MACA) since 1994 (Fry and Jernigan 2007). Initially, the primary areas of concern were those cave regions near to artificial cave entrances. These regions were reasonably expected to be impacted by changes in the artificial entrances (specifically, replacement of existing single doors with double-door airlocks). Data were collected (at one point per station) before and after the retrofits to detect associated impacts on the cave climate. Later, in 1996, some of these single-point data collection stations were established in the Historic Section of Mammoth Cave (whose entrance is a modified natural entrance). The data collected in the Historic Section were, in subsequent studies, used to detect impacts of an entrance modification upon air temperature and, at some locations, relative humidity. Further, one of the data collection stations (the station nearest the entrance) also included wind velocity sensing equipment. For measurement of wind speed, MACA’s hydrologist designed and built a datalogger-compatible wind speed sensor. For wind direction, an off-the-shelf, datalogger-compatible wind vane was used. The air temperature, relative humidity, and air velocity measurements collected were useful in ascertaining management’s impacts on the cave environment at each of the stations.

In 2000, MACA became the prototype monitoring park for the cave/karst biome within the Long Term Ecological Monitoring program. Through the network’s vital signs ranking process, cave air quality (as the vital sign was originally known) was selected as a high priority vital sign at MACA. In 2002, NPS Inventory and Monitoring personnel, in partnership with USGS-BRD

personnel, began development of the cave air quality protocol through discussions and exploratory data collection.

The first sampling designs constructed were for cross-sectional airflow monitoring. In the first attempt at an airflow monitoring design, the investigators attempted to collect, within about an hour, a grid-sampling of instantaneous airflow measurements within a cave cross-section. The intent was to estimate (or mathematically model) the volumetric change per unit time of air through the cross-section (i.e. a volumetric exchange rate for air). Data collected seemed to indicate that regions existed within a cross-section wherein air velocities were higher than surrounding regions (see Figure 9). That is, it seemed that the air in some parts of the cross-section was moving faster than the air in other parts of the cross-section. This behavior is theoretically feasible and subsequent observations of other cross-sections yielded similar results. However, closer inspection of the data revealed that air velocity fluctuated significantly in time from one measurement to the next. This temporal variability meant there was no certainty about the relative size of the air velocity values collected for any given point in the cross-section. As a result, no reliable spatial models for air velocity could be generated, thereby preventing the construction of accurate mathematical models for the estimation of a cross-section's volumetric exchange rate.

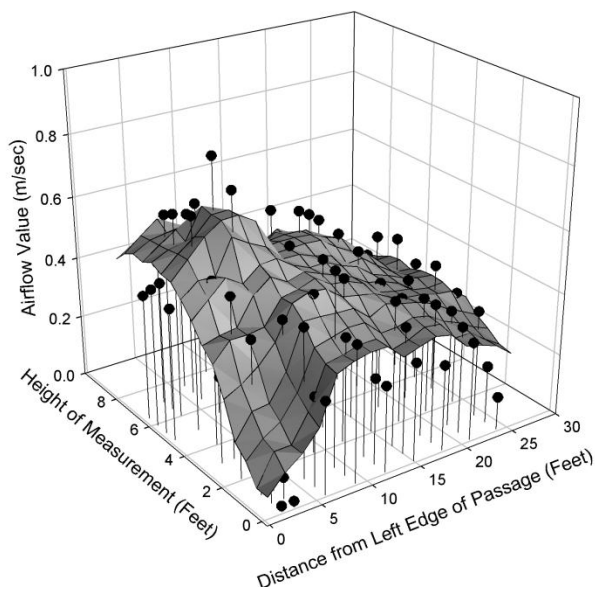


Figure 9. A first attempt at a cross-sectional airflow sampling design. Data were collected instantaneously from a cross-section in the Historic Entrance to Mammoth Cave. Dots represent air velocity data collected. The surface is an interpolated best fit surface for the set of velocity data.

The spatial/temporal instability of cross-sectional airflow was further explored during the winter, spring, and summer of 2005. During those periods, three anemometers were placed for about two weeks at a time into one of Historic Mammoth Cave's main entrance passageways. Data were collected on five minute intervals from each of the three anemometers which were distributed evenly through the cave cross-section. Each of the data streams (Figure 10) contained significant temporal noise, supporting the idea that spatial modeling of air velocity

within a cross-section would not be possible through instantaneous “grab” sampling around the cross-section. Interestingly, though, each of the anemometer’s time series shared common trending and seasonality. This meant that if the noise could be ignored or averaged-out, the resultant data streams co-varied with one another. And, if a management action had an impact upon a cross-section’s airflow, it should do so uniformly (nearly, at least) through the cross-section. So, if the air velocity were reduced by half, for example, at one of the points in the cross-section, it should be reduced by about half in the remaining portions of the cross-section. The key point being this: if at every point within a cave cross-section the airflow is behaving similarly, measuring airflow at one point within the cross-section is sufficient to understand the cross-section’s airflow patterns. This condition of similar behavior throughout the cross-section is not, however, always the case. It is not uncommon, for example, to have air at a cave’s ceiling moving in one direction and air at the floor moving in the opposite direction. This bidirectional flow would dictate that two anemometers are necessary to characterize airflow within such a cross-section. More generally, then, if a cross-section contains multiple zones (or regions) of similar airflow, then each zone should be sampled with an anemometer. This is exactly the approach to monitoring airflow that the investigators are presenting.

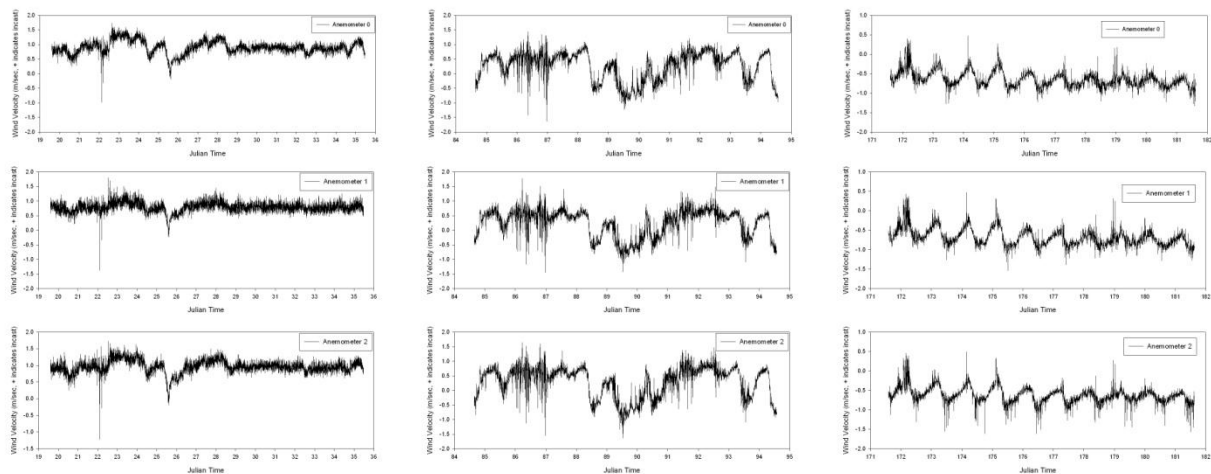


Figure 10. Three airflow sampling periods in 2005 (from left to right, January 19 through February 4, March 25 through April 4, and June 20 through 30) suggesting that (1) airflow data are too noisy for our initial grab sampling approach, and (2) airflow across this particular cross-section covaries temporally.

About midway through the development of the airflow sampling design and methodology, the investigators began to discuss development of the same for air temperature and relative humidity. The investigators concluded, after some discussion, that management’s concerns over air temperature and relative humidity were because of the impacts of these parameters to cave resources such as crickets, bats, and wooden artifacts. All of these resources spend most of their time (all of the time, of course, in the case of wooden artifacts) near a cave passage’s surface (that is, the floor, ceiling, or wall). The decision was therefore made to develop sampling tools for the monitoring of air temperature and relative humidity close to cave surfaces.

Beginning in February 2005, spatial sampling of air temperature and relative humidity was completed in one of the cave rooms within the MACA system. Biweekly sampling (approximately) was conducted by interns for about one year. In addition to collecting air quality parameters in a rectangular grid along the surface of interest (in this case, the ceiling), the interns collected data on biota existence at each point along the grid. The particular biota of interest was cave crickets. The grid used was approximate in cell size but each point on the grid was sampled, so chance dictated that some of the data collection points would be host to a patch of crickets and some of the points would not host any crickets. The existence or non-existence of crickets was noted on a field form, and these data were later entered into a database. Additionally, patches of crickets not coincident with the grid were opportunistically sampled. The screen capture below (Figure 11) shows some of the data that were collected (please note that the Access database shown is an early prototype and is not the version that accompanies this protocol). T-tests to compare the temperature/humidity at crickets and non-crickets points suggest that the spatial clumping of crickets commonly observed is not a response to spatial variability in air temperature or relative humidity (as can be detected by the Vaisala HMP45C, which is the air temperature / relative humidity probe that we used). These results are illustrative of additional benefits provided by spatially sampling air temperature and relative humidity.

Year	Julian Day	Time (hhmm)	Site Number	Bearing(degrees)	Distance(m)	Crickets? (y/n)	Air Temperature	Relative Humidity
2005	174	1014	1	205	14.28 y		14.82	90.1333333333333
2005	174	1015	2	201	13.75 y		14.71	90.9
2005	174	1018	3	198	13.29 n		14.49	92.65
2005	174	1019	4	192	12.41 n		14.4766666666667	93.3166666666667
2005	174	1020	5	182	11.83 n		14.4033333333333	93.3
2005	174	1021	6	175	11.51 n		14.4033333333333	94.0666666666667
2005	174	1023	7	167	11.44 n		14.3842857142857	94.1142857142857
2005	174	1024	8	163	11.68 n		14.3166666666667	93.5833333333333
2005	174	1027	9	206	13.17 n		14.13	94.8
2005	174	1028	10	207	12.67 n		14.16	95.4333333333333
2005	174	1037	11	201	11.42 n		14.365	94.5666666666667
2005	174	1038	12	195	10.6 n		14.3971428571429	94.6142857142857
2005	174	1039	13	180	10.16 n		14.525	94.6666666666667
2005	174	1041	14	173	9.71 n		14.5685714285714	93.5714285714286
2005	174	1042	15	162	10.07 n		14.4983333333333	93.1333333333333
2005	174	1043	16	180	10.82 n		14.5166666666667	94.0333333333333
2005	174	1048	17	216	11.75 y		14.2466666666667	94.4
2005	174	1049	18	219	11.06 y		14.2516666666667	94.8666666666667
2005	174	1050	19	208	10.54 n		14.28	95.4166666666667
2005	174	1051	20	207	9.65 n		14.2966666666667	95.0666666666667
2005	174	1052	21	205	9.12 n		14.3228571428571	95.1285714285714
2005	174	1053	22	193	8.38 y		14.33	94.8833333333333
2005	174	1056	23	182	8.47 n		14.2185714285714	94.9571428571429
2005	174	1111	24	172	7.13 n		14.6866666666667	93.4333333333333
2005	174	1112	25	170	7.57 n		14.655	92.7166666666667
2005	174	1115	26	222	9.97 y		14.5466666666667	94.2
2005	174	1115	27	221	10.95 y		14.5557142857143	94.5428571428572
2005	174	1116	28	222	8.58 y		14.5116666666667	94
2005	174	1118	29	221	9.64 n		14.4628571428571	94.1142857142857
2005	174	1119	30	213	8.41 n		14.4585714285714	94.6142857142857
2005	174	1119	31	206	7.44 n		14.4566666666667	94.6
2005	174	1120	32	190	6.71 n		14.45	95
2005	174	1122	33	174	6.48 y		14.4766666666667	95.2166666666667
2005	174	1123	34	162	6.35 n		14.4385714285714	95.0142857142857

Figure 11. Typical spatial air temperature and relative humidity seasonal sampling data.

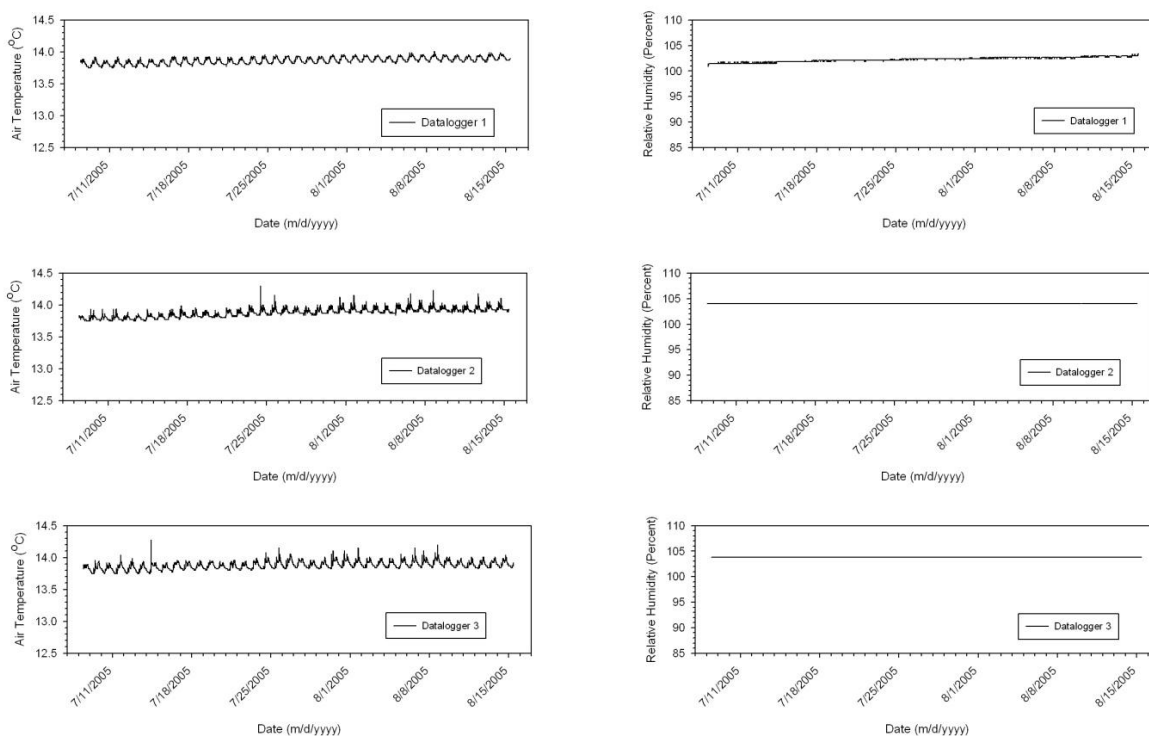


Figure 12. Air temperature and relative humidity data collected by three HOBO dataloggers in the same cave room within the Mammoth Cave system. Each datalogger was at a different location within the cave room. Note that that all of the air temperature data streams and relative humidity data streams co-vary.

In addition to collecting these spatial data, air temperature and relative humidity data were also collected using three HOBO dataloggers (these dataloggers are discussed in more detail later in the narrative) in different locations within the tested cave room. Two of the dataloggers were located in one corner of the cave room (one datalogger was located at the cave floor while the other datalogger was located directly above the first and near the cave ceiling). The third datalogger was placed at another location within the cave room and near the ceiling. The air temperature and relative humidity at all of the dataloggers co-varied with each other over time (see Figure 12). It should be noted that the relative humidity recorded by HOBO dataloggers is 104.1% in saturated environments or if the sensor is coated with water. The investigators placed these dataloggers upside-down to make certain that water would fall away from the sensor. So, the dataloggers at our test site were in a saturated environment. In the case of relative humidity, then, covariance is indicated by the fact that all three dataloggers show the cave space was saturated.

We did not test our approach in a non-saturated cave space, but the fact that relative humidity tends to co-vary with air temperature in cave spaces at MACA strongly suggests that in a cave space where air temperatures co-vary, relative humidities will also co-vary. This covariance of relative humidity with air temperature is supported by the plots in Figure 13. The plots use data collected during the 1996 – 2000 sampling run within the Historic Section of Mammoth Cave.

The r-squared values for the Corkscrew data and the Rotunda data are 73% and 87%, respectively, indicating good correlation between the two parameters.

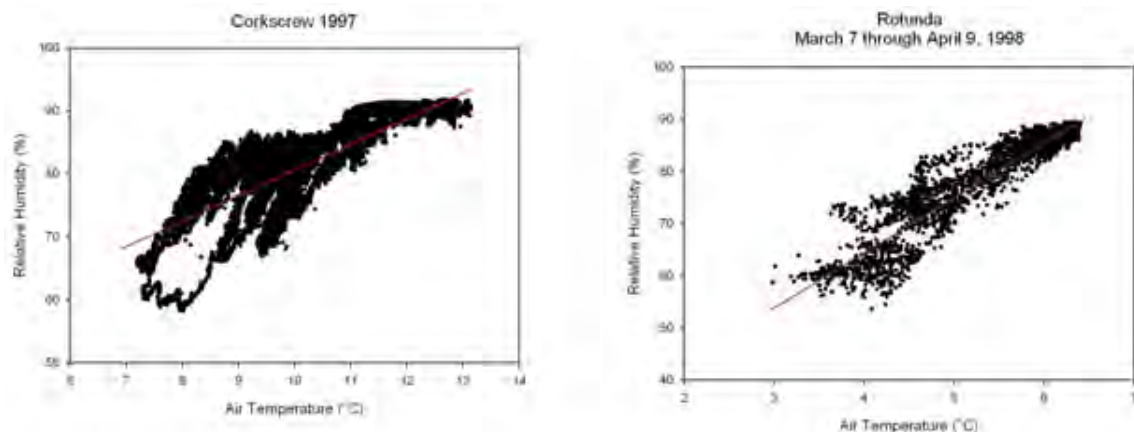


Figure 13. Covariance of air temperature and relative humidity in the Corkscrew and Rotunda. Both sites are in the Historic Section of Mammoth Cave. The red lines are lines of best fit. The r-squared values for the Corkscrew data and the Rotunda data are 73% and 87%, respectively, indicating good correlation between the two parameters.

For all data collected by the HOBOS (air temperature and relative humidity), temporal noise is minimal. This minimal noise and the data's covariance suggest that data from any one of the dataloggers can be used to predict the other two. That is, the at/rh time series from one location can be offset to produce the at/rh time series for either of the other locations. So, the approach chosen by the investigators to at/rh monitoring is to:

1. "Seasonally" collect spatial air temperature and relative humidity data along the surface of interest.
2. Place and collect at/rh data from a datalogger at a convenient location within the cave room of interest (near the surface of interest, if possible).
3. Generate a modeled time series for the surface of interest by offsetting the datalogger measurements by the mathematical difference between
 - a. The mean value of the seasonally collected spatial data.
 - b. The value collected by the datalogger at the time of the seasonal data collection event.

Modified versions of this at/rh sampling design and its associated methodologies are currently in use at MACA. The cave cricket protocol and (now shelved) cave beetle protocol each contains an air temperature/relative humidity component. For cave cricket monitoring, air temperature and relative humidity data are collected at each cricket cluster of which a photograph is taken. This approach allows comparison of air temperature and relative humidity at a cluster to its individual count, sex ratio, etc. The approach will also suggest atmospheric conditions that cave crickets will tolerate. For cave beetle monitoring, air temperature and relative humidity data were collected at each pitfall trap site when the traps are set out. This approach would suggest atmospheric conditions under which cave beetles are active and make regular use of a site.

Also, single point air temperature monitoring is being conducted at a network of sites within MACA, including sites in Historic Mammoth Cave, Frozen Niagara and “lesser caves” within MACA. An example of the data is shown in Figure 14.

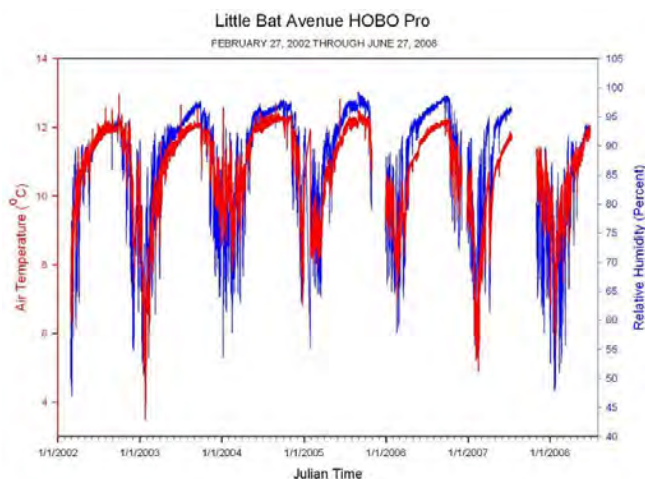


Figure 14. Several years of air temperature and relative humidity data from a site in the Historic Section of Mammoth Cave.

Measurable Objectives

This protocol presents sampling methodologies and instructions for using specific sampling and mapping technology to be used to collect cave atmospheric data. This protocol also provides basic (generic or suggested) sampling design and data management guidelines. The protocol’s main objective is to provide for monitoring of cave air parameters in two major contexts: in adaptive and user or management-selected sampling air activities (such as to assess conditions in an area to evaluate current or proposed management activities) and in support or conjunction with other cave monitoring activities (such as beetle, cricket, rat, or bat monitoring).

The specific **monitoring questions** that will be addressed by this protocol include:

1. How does air temperature and relative humidity vary temporally and spatially and what are potential drivers for this variability?
2. What are the responses of cave biota to temporal and spatial variability in cave air temperature and relative humidity?
3. What are the impacts of management actions upon spatial distribution of air temperature and relative humidity along cave surfaces?
4. What are the impacts of management actions upon air velocity at sampling points within a cave cross-section?

The specific **monitoring objectives** for this protocol are:

1. Provide a modeled time series of mean air temperature and standard deviation along the surface of interest.
2. Provide spatial air temperature and relative humidity data as well as collateral spatial data (if desired by the user) on biota existence.
3. Provide representative air velocity data for a cave cross-section.

Sampling Design

The Sampling Designs

Sampling designs for the following efforts are presented:

- Spatial sampling of air temperature and relative humidity along a cave surface.
- Temporal sampling of air temperature and relative humidity using dataloggers that remain on site for extended periods.
- Temporal sampling of cross-sectional air velocity with “seasonal” assessments of spatial heterogeneity of the cross-section’s airflow field.

One approach to sampling at/rh is to place a datalogging sensor at the desired location near the surface of interest and allow the sensor to collect data over time. This is the approach presented here with two enhancements:

1. In areas where the sensor can not easily be placed near the surface, the project manager may select some other, more convenient, location within the cave room. In this case, the at/rh data along the surface can be extrapolated.
2. The spatial variability of at/rh within the cave room and along the surface of interest may be assessed.

Attachment of sensors to the surface of interest is frequently difficult in caves. This is due to the need to attach the sensors through the use of screws or nails. Many times, there is simply no crack or crevice in which the screws or nails may be inserted. An alternative approach is to place the datalogger/sensor near the floor or on a small stand. This arrangement allows convenient access to the datalogger for servicing and data transfers and does not damage the cave surface. To determine the temperature/humidity along the surface of interest, temperature/humidity are periodically measured simultaneously both near the surface of interest and at the datalogger. The difference in the values between the two locations is assumed temporally constant between the periodic measurements, and that difference is used as an offset that is added to the datalogger measurements. For example, if air along the surface of interest happens to be two degrees warmer than the air at the datalogger, then two degrees are added to the datalogger measurements.

It is commonly stated that air temperatures in caves are constant over time and space (with the exception of areas within the variable temperature zone). Even within the constant temperature zone, this is not exactly the case. In order to assess the amount of spatial variability within a cave room, designs and methods are presented for spatial data collection along the surface of interest within a cave room of interest. Over the course of a sampling session, data are collected spatially using a rectangular grid with the grid spacing determined by the project manager (at MACA, we used a 2 meter by 2 meter grid for our test). The standard deviations are then computed for the air temperature and relative humidity in that set of data. These standard deviations are used as indices for the amount of spatial variance in each of the parameters sampled.

The air velocity sampling design consists of sampling air velocity over time at multiple points within a given cross-section. The number of air velocity sampling points depends upon the number of homogeneous regions in the air velocity field. We define a homogeneous region as one over which air velocity values co-vary over time and are similar in magnitude. One anemometer should be used for each region of the air velocity field. Determination of a cross-section's air velocity field is accomplished by periodically sampling within the cross-section with several anemometers (we allow as many as six) over about a two week time frame. Analysis of these data streams will show either similarity or dissimilarity amongst the airflow behaviors at the anemometers. Locations with similarly behaving airflow will be pooled together and the location with the tendency to have the fastest air speed will be used to represent air velocity within the pool. Air velocity will be sampled at the representative locations over time until it is necessary to reassess the cross-section's air velocity field.

This design allows management to better detect impacts to airflow within a cave cross-section (when compared to sampling air velocity statically with only one anemometer in a cross-section). Periodically sampling at multiple points in a cross-section greatly increases the likelihood that an impact is detected. This increased likelihood is due to heterogeneous flows within cross-sections, wherein one region of the air velocity field may be impacted by the management action but other regions may not be impacted. Ideally, multiple anemometers could remain in place for the entire year. This, however, is impractical and expensive. Also, a cross-section's air velocity field is likely to change over the course of a year, meaning that the number of homogeneous regions is likely to vary and the individual regions to move. In order to collect data from each of the regions that could exist over the course of a year, many anemometers could be necessary. So, the approach chosen is to periodically "hunt" for the regions in a cross-section. As many as six anemometers are placed in the cross-section at the beginning of each season to hunt for these regions. Once found, an anemometer is placed in each region and left there until the upcoming season.

During the developmental phases of this protocol, we are developing an alternative air velocity sampling design. That development has stopped but may be resumed in the future. The design may be referred to as an automated vertical stratification sampling design. As suggested by its name, the sampling design searches for vertical strata in the airflow field by measuring air velocities along a vertical axis. This approach will provide air velocity data that are from various heights, thereby allowing us to detect multidirectional flow within a cross-section as well as the height at which flow reversals occur. It should be noted that while multidirectional flows may occur along a horizontal axis, it is more common that airflow fields possess vertical strata. Also suggested by its name, the sampling will occur automatically via the use of dataloggers and an automated instrument lift system that is being developed with the Department of Engineering at Western Kentucky University (WKU). More information on the lift system may be found in the subsequent section "Air velocity sampling: seasonal mode."

It should be noted that the distribution in space and over time for all sampling designs (at/rh and airflow sampling) that are provided are examples of possible and reasonably adaptable approaches. These spatial and temporal distributions may be modified to fit and meet user needs, scope and scale of the site, and/or other considerations that are specific to the user's

application. The details for the use of designs are presented in the appropriate standard operating procedures.

Rationale for Selecting these Sampling Designs over Others

This protocol presents sampling designs and methodologies to collect data that are enhancements of MACA's historic cave atmospheric data. Rather than collect data at one point per cave room, air temperature and relative humidity data may be periodically collected over a rectangular grid near the surface of interest and consisting of many points per cave room. Each point is spatially referenced with collateral data such as biota existence. Air temperature/humidity data are also collected using a datalogger that permanently resides on-site and collects data continuously. Air velocity monitoring data will continue to be at one point per cross-section where airflow is homogeneous across the cross-section, but, in cross-sections with heterogeneous airflow, one point per homogeneous region will be sampled (resulting in multiple points per cross-section).

Seasonally, air temperature and relative humidity may be sampled in a rectangular grid along a chosen surface. For flexibility, the cave space and surface along which data are to be collected may be chosen adaptively or discretionarily by management. For example, the surface may be chosen to address management concerns over biota that exist along the surface or to collect data along a surface that is likely to be impacted by some management action. The rectangular grid was chosen since it is the easiest possible way to uniformly and non-subjectively distribute sampling effort in variably complex fields. Other designs have been avoided due to complexity of application or non-uniform sampling over the cave space. Sampling along a polar grid, for example, is easy to execute in the field but results in lower density of sampling effort as the sampler moves away from the center of the grid. Therefore, we avoided polar sampling approaches in order to maintain uniform intensity of sampling.

Collection of continuous air temperature and relative humidity data could have been completed either by forcing the datalogger placement to be near the surface of interest or by allowing the datalogger to be placed in a more convenient place if necessary. In our tests, the investigators chose the second approach. This approach allows for easier installation and easier access to the datalogger for servicing and data transfers.

The general air velocity sampling design was chosen for its ability to detect regionalization of a cross-section's air velocity field. Not only can the regionalization be detected, but by collecting air velocity data in each of the regions, the relationship between air velocities of the regions may be assessed. The sampling design also enhances our ability to detect management impacts upon a cave's atmospheric conditions, as impacts may vary region-to-region. The alternative approach (statically sampling in one location within a cross-section), however, is frequently not representative of the air velocity field through the cross-section, and so has been avoided.

Grid spacing for seasonal at/rh sampling and anemometer placement during seasonal sampling/mode may be adaptively adjusted provided that any spatial heterogeneity may be detected. For example, a priori knowledge of airflow in Houchins' Narrows (our airflow test site within MACA) together with the cross-section's size and location suggested that only a few anemometers would be sufficient. Houchins' Narrows has a relatively small cross-section at our test site and the passage channels air from the outdoors into MACA's Historic Section. Because

the passage is the interface between the cave and the outdoors, large volumes of air frequently flow through the passage, and, because of our site's small cross-section, the velocity of the air can be quite large. The large volume exchange/velocity through that passage is a result of high pressure heads that exist at one end of the cave passage or the other, as indicated by flow direction. Due to the pressurization at one end of the passage, one would not expect multidirectional flow through that end. And since Houchins' Narrows only gets smaller (although only slightly) as one moves away from its ends, multidirectional flows would not be expected anywhere in the passage. This would suggest relatively uniform airflow fields in cross-sections throughout the passage. In summary, we expected airflow in Houchins' Narrows to be relatively uniform, so we did not place anemometers in vertical strata or near the ceiling. Similar knowledge of some of the more in-cave and larger passages in Historic MACA would suggest that at least one anemometer should be near the ceiling and one should be near the floor to detect suspected bidirectional flows.

Site Selection

This protocol provides only general rules for choosing sampling locations. Specific sampling locations are determined or identified in two ways depending on their function. In cases where air sampling is in support of other monitoring protocols, sampling sites will be determined by site locations selected for the other protocol. In management assessment cases, site locations will be provided by management and depend upon caves and areas of caves that are of concern. While some limits do apply, managers are free to pick the sites at which air temperature, relative humidity, or air velocity data are collected. The sampling methodologies and designs presented are appropriate and adaptable for most potential sampling locations. For a list of location limitations, see SOP #3.

Sample Frequency and Replication

The frequency of seasonal air temperature and relative humidity data collection events are determined by management needs and to capture any changes in air temperature and relative humidity distribution that might occur as the year progresses. It is suggested that these events occur at least one time each for winter, spring, summer, and fall. It may also be unnecessary to repeat these sampling efforts each year. For example, if a cave room is known to have similar at/rh values from year-to-year, then spatial sampling within the room may only be necessary during the first year of the monitoring effort and subsequent years may be skipped. It is strongly recommended, however, that reassessments are periodically (every 5 years perhaps) conducted to insure that the spatial distribution has not changed. Alternatively, other sampling frequencies may be implemented as needed to support specific needs of other monitoring activities (i.e. sampling in conjunction with weekly beetle monitoring).

Air velocity monitoring is conducted continuously with periodic assessments of cross-section heterogeneity. These periodic assessments should be completed seasonally, about one-third of the way into a season. This schedule allows the detection of cross-section heterogeneity early in its development and assures that anemometers will be in place to collect data in all regions of the air velocity field for most of the season. An example schedule is provided in a table in the subsequent section "Field schedule and annual workload."

Field Methods

Field Season Preparations, Field Schedule, Site-Check, and Equipment Setup

Prior knowledge of sampling procedures and locations is essential for efficient and consistent sampling efforts. Therefore, project crew leaders and crew members should be trained and refreshed (SOP #1 “Training of Field Personnel”), particularly if new personnel join the sampling crews or if intervals between sampling events are $\geq$ six months.

In general, sampling events associated with repeated-sample, site monitoring activities will be scheduled by the project leader in one-week blocks within each of the 12 months by 31 December for the upcoming calendar year. Other sampling activities and events, such as those to assess sites at specific management request, will be scheduled for appropriate time frames and intervals on a per-event basis. Specific sampling schedules and intervals may be adjusted to account for inclement weather, personnel workloads, etc. Sampling routes (the sampling order) for each crew will be finalized one or two days beforehand (incorporating information obtained during the cave-check described in the next paragraph) in order to maximize efficiency and minimize travel times.

A day or two before the scheduled sampling event a project crew leader and/or a crew member should conduct pre-sampling cave-checks of all remote cave entrances (SOP#2 “Pre-Sampling”, Site-Check of Sampling Sites). The purpose of these checks is to confirm that all sampling caves can be located and accessed (i.e., no safety hazards or roads blocked). Also, particularly difficult to locate caves can be temporarily marked with a piece of colored survey ribbon placed in the vicinity ($\geq 15\text{m}$) of the cave entrance to enable easy location of the cave during sampling. Upon return from the field, the crew leader/member will give a copy of any written notes that may impact sampling logistics to the project leader, and discuss options with the project leader. Based on outcomes of the discussion, appropriate adjustments will be made prior to the upcoming sampling event.

In order to reduce lost time and perhaps lost data, a pre-trip checklist is provided (SOP #2 “Pre-Sampling”, Checklist 2). The crew leader must check each item on the list, particularly supplies, at least one week before sampling, in case supplies are needed, and again the day before the trip for final details. All of the equipment and supplies listed in this checklist should be organized and made ready for each trip into the field, and copies of the appropriate field data form (all field forms are contained in an accompanying folder) should be made. Most equipment maintenance and repair/replacement is routinely performed as a post-sampling task—this check serves as an assurance of current readiness. As the crew leader prepares to depart for the field, the list should be checked again and reconciled against supplies and equipment being loaded up to assure nothing is being left behind.

Sampling Methods – Dataloggers and Sensors Used to Collect Atmospheric Data

We are providing methodologies to sample air parameters in different contexts: air temperature and humidity near cave surfaces using handheld sensors and HOBO dataloggers as well as air velocity within a cross-section using ultrasonic anemometers deployed on tripods and towers. Each application has a specific methodology based upon the technology being used. A key

component of most of this sampling is Campbell Scientific's CR10X datalogger, discussed below.

Please note: this protocol was originally written in March 2007 when the CR10X was still available. As of February 2011, the CR10X is no longer available. Those users with CR10X dataloggers may still use those dataloggers. However, those without a CR10X will need to purchase an alternative. We recommend the CR1000 from Campbell Scientific.

Data collection will be automated and datalogger driven whenever feasible. This approach streamlines data collection, largely eliminates the need for data entry from data forms to a database, and significantly improves data quality since the possibility of human error is largely removed. Generally, dataloggers were chosen for their ability to collect data of interest, reliability, and ease of use. Two dataloggers are used: the CR10X by Campbell Scientific and the HOBO Pro RH/Temp system by Onset Computer Corporation. The CR10X is a datalogger only and does not include any built-in sensors (while the HOBO includes integrated air temperature and relative humidity sensors). It is therefore necessary to purchase separate sensors for the CR10X and each of its assigned tasks. For the collection of spatial at/rh data, Vaisala's HMP45C probe was chosen, and for the collection of air velocity data, Gill's Sonic Anemometer was chosen.

This CR10X by Campbell Scientific (Figure 15) is a versatile unit capable of controlling a wide variety of hardware and reliably storing data for extended periods of time. As just mentioned, this datalogger is used to collect spatial air temperature/relative humidity data and all air velocity data. Sensors are attached to the datalogger via lug terminals on its wiring panel, and, for the sensors presented here, power is provided to the sensors through lug terminals as well. Programs for the datalogger are written by the user, and those programs needed for the at/rh and air velocity sampling are provided.



Figure 15. Campbell Scientific's CR10X Datalogger for Measurement and Control. Image downloaded from www.campbellsci.com

The sensors chosen by the authors are suitable for the detection limits that we set. We have chosen to address, through this protocol, large-scale changes in the parameters that we propose to measure. We have chosen "large-scale" detection limits since these are the types of change to which management can reasonably be expected to respond. A small-scale change in air temperature, for example, of 0.25 degrees Celsius may be detected with the proper instrumentation, but we have no way of recommending to management the action that should be taken to address a temperature change of this magnitude. Further, such small-scale changes are likely to occur naturally in a cave space, so that we have no way of differentiating between

anthropogenically induced and natural changes. Since our focus is on providing support for management decisions, these small-scale changes are not the subject of this protocol. Our chosen detection limits for the parameters measured and the accuracies of the associated instrumentation are presented in Table 2.

Table 2. Detection limits with our selected instrumentation.

<i>Parameter</i>	<i>Desired Detection Limit</i>	<i>Instrument</i>	<i>Nominal Instrument Accuracy</i>
Air temperature	1.0 °C	Vaisala HMP45C	± 0.35 °C
Air temperature	1.0 °C	HOBO Pro RH/Temp	± 1 °C
Relative humidity	5.0% for 0-90% RH N/A for >90%	Vaisala HMP45C	± 2 % for 0-90 % ± 3 % for >90 %
Relative humidity	5.0% for 0-90% RH N/A for >90%	HOBO Pro RH/Temp	± 3 %
Wind speed	0.4 m/sec	WINDSONIC-L 2-D Sonic Wind Sensor	± 2 % of measured speed
Wind direction	90 compass degrees	WINDSONIC-L 2-D Sonic Wind Sensor	± 3 compass degrees

The HOBO Pro RH/Temp system by Onset Computer Corporation (Figure 16) consists of a datalogger with integrated air temperature and relative humidity sensors. The complete system is commonly referred to as the datalogger. This “datalogger” will be used to collect data “continuously.” The datalogger was chosen for its low cost, ease of use, and reliability. These loggers have been used by Bat Conservation International to study at/rh in areas inhabited by bats. They are also currently used by the National Park Service at MACA to assess current conditions in Historic MACA.



Figure 16. Onset Computer Corporation’s HOBO Pro RH/Temp Datalogger. Image downloaded from www.onsetcomp.com.

For the collection of spatial air temperature and relative humidity data, the Vaisala HMP45C probe (Figure 17) was chosen. This Vaisala probe is a fast-response unit that has accuracies of ±0.2 °C and ±2.0%. The probe is commonly available and easily connected to the Campbell CR10X. The use of this probe allows crew members to quickly and easily move through a cave space. However, the relative humidity sensor does suffer a common problem of relative humidity sensors: the sensor’s accuracy in high humidity environments is poor. As a general rule, humidity values at ninety percent or higher are considered equivalent and the environment in which the data are collected is considered saturated. It should be noted that relative humidity in many areas within cave systems are routinely recorded at or above the low-to-high 90% range, and that these spaces may thus be functionally saturated in terms of possible effects on biota and/or cultural artifacts.



Figure 17. Vaisala's HMP45C Temperature and RH Probe. Image downloaded from www.campbellsci.com.

Several technologies are available for measuring air velocity, from homemade units (as mentioned in the historical development section) to state-of-the-art units. This protocol uses a sonic anemometer (Figure 18). The sonic anemometers used in this protocol create an ultrasonic sound field and measure Doppler shifts in the sound field to determine both wind speed and direction. These units were chosen for their low wind speed threshold, accuracy, and their relatively low price. The anemometers used in this protocol are also easily connected to Campbell Scientific's CR10X.



Figure 18. WINDSONIC-L 2-D Sonic Wind Sensor. Image downloaded from www.campbellsci.com.

Sampling Methods

There are two types (or modes) of data collection each for at/rh sampling and air velocity sampling. Each mode uses different methods to establish sensor placement as well as different field forms. These modes are:

- Air temperature and relative humidity spatial sampling events
- Air temperature and relative humidity temporal sampling by a HOBO
- Air velocity sampling: seasonal mode (to determine a cross-section's spatial airflow patterns or, equivalently, whether its flow field is homogeneous or heterogeneous)
- Air velocity sampling: monitoring mode (at seasonally determined locations in the cross-section)

The first, third, and fourth data collection modes all make use of CR10X dataloggers. The datalogger program for each of these modes contains user-adjustable constants to indicate where

(geographically) the data are collected. These constants include cave code, landmark code, and cross-section code. Each of the constants is included as part of the datalogger's output stream, thereby ensuring that the data collection location of a raw data file is known.

Air temperature and relative humidity spatial sampling events

In this case, air temperature and relative humidity are sampled using the Vaisala HMP45C probe. The probe is placed within plots along the desired surface and data are collected for some predetermined amount of time. As illustrated in Figure 19, the locations of sampling plots are established using two lasers (which can be purchased at local hardware stores). The first laser line remains in place through the sampling event and serves as a reference (referred to as axial) line perpendicular to which the second laser line is directed. The second laser line establishes transects along which data are collected. We used an ~2 meter length of PVC pipe to space measurements along the transect line. This PVC pipe was also used to lift the instrument probe up to the surface along which we were measuring (in our test case, the ceiling). The PVC pipe was also used to advance the transect line down the axial line as sampling along each transect line was completed.

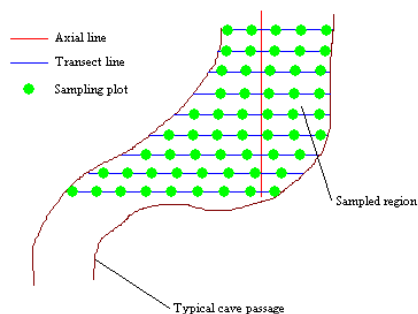


Figure 19. Typical at/rh sampling grid.

As a side note, we suggest collecting at/rh data for ~35 seconds per plot, and the CR10X program provided assumes this collection interval. The CR10X program provided temporarily stores at/rh values each second, and, at the end of a five second interval, these one-second data are averaged and the results are permanently stored to the datalogger. Once the sampler is in place and ready to collect data, one of the datalogger's "flags" is activated and an internal timer tracks the amount of time the flag has been active. Once the flag has been on for 36 seconds, the datalogger automatically deactivates the flag and the sampler moves to the next sampling plot on the grid.

Because the grid spacing is user-selected, specific to cave space and surface, approximate, and it is unlikely that subsequent sampling events will result in the same grid, it is necessary to track the spatial location of each plot sampled as sampling is conducted. This mapping of the sample plots allows post hoc spatial analyses to be completed. For example, one of the questions we at MACA have is whether local high spots on cave ceilings have higher temperatures than adjacent, lower parts of the cave ceiling. To answer this question, we can, in the future, map the cave ceiling as a three-dimensional surface and then overlay onto that map the data from past at/rh sampling events. Visual inspection and neighborhood analysis will allow us to answer the post hoc question.

Methodology does not exist for quickly, efficiently, and accurately mapping sampling plots in caves. Our initial approach to this problem was to:

1. Establish a permanent landmark within each cave room sampled. Landmark points are surveyed into the cave space in reference to geologic features and/or existing marker monuments.
2. Use a standard magnetic compass to measure the azimuth to the point sampled from the landmark. Magnetic compasses measure precisely from any point within a cave. So, using a magnetic compass to record the azimuth of sampling plots relative to some landmark is precise and repeatable. That is, if a sampling plot is 170 degrees off magnetic north as measured by compass today, then that sampling plot will be at 170 degrees off magnetic north tomorrow.
3. Use a digital rangefinder to measure the distance from the landmark to the sampling point.
4. On a field form, write the azimuth and distance for each plot.

This initial approach, while supplying the essential data, is not efficient or immune to compass reading and transcription errors. To get around these problems, the investigators entered discussions with staff from the Engineering Department at Western Kentucky University (WKU) to design and construct datalogger-compatible mapping instrumentation. This mapping instrumentation can digitally measure and store into a Campbell Scientific CR10X datalogger (coincident with the at/rh data) the following information:

1. Azimuth
2. Elevation (to enable measurement of ceiling height, for example)
3. Distance

These three pieces of data form the basis for a spherical coordinate system that can be used to measure many spatial phenomena. For at/rh sampling, the mapping information will be collected simultaneously with the at/rh data. The hardware will be tripod-mounted, and a crew member will simply need to site, through a laser pointer contained in the rangefinder, the device onto the sampling plot. Azimuth, elevation, and distance data will automatically be stored into the datalogger. This approach greatly streamlines data collection and reduces the need for hand entry of data onto a field form, thereby greatly reducing transcription errors. This equipment is currently in development with a prototype nearly complete. Upon receipt of properly functioning mapping equipment, this protocol's narrative and appropriate SOP's will be modified to include operational details of this equipment.

The only data that can not be digitally captured in the field are collateral data, such as data on biota existence. These data are written onto a field form and hand-entered into a database at a later time.

Air temperature and relative humidity temporal sampling by a HOBO

The placement of the HOBO datalogger that is permanently stationed in a cave room of interest must be done so in one of three ways. The easiest way is to simply place the datalogger on the floor. If this option is chosen, the datalogger should be turned upside-down (to avoid having water collect on the logger's humidity sensor) and suspended between two small rocks or boards

to avoid contact with the cave floor. If the datalogger is in direct contact with a cave surface, heat may conduct into or out of the datalogger, thereby distorting the air temperature measurement. Please note that in caves with packrats or other opportunistic biota, this placement may not be optimal as the datalogger may be dragged into other parts of the cave or damaged through chewing. A stand may also be built, onto which the datalogger may be mounted. If this option is selected, the datalogger should be thermally isolated from the stand, particularly if the stand is a good conductor of heat (as is metal). A third option for mounting the datalogger is direct attachment to a cave wall or the ceiling. This option uses toggle bolts or nails through appropriately sized crevices in the cave surface of choice. Please note that this method can damage the cave surface and should be avoided in areas with delicate formations. If this option is chosen, the datalogger will need to be thermally isolated from the cave surface. We suggest that the HOBO should not be allowed to touch the surface, so that no conduction can take place. This separation may be accomplished by putting spacers between the back of the HOBO and the cave surface. The toggle bolts or nails should pass through the spacers.

The location of the datalogger relative to the landmark within the cave space should be documented. This is accomplished through use of the mapping instrumentation provided by WKU. Azimuth, elevation, and distance from the landmark are read from the mapping device's LCD panel and then written onto a site setup field form.

The field form used to document a HOBO site's history contains several pieces of information. These data include the spatial location of the datalogger, the servicing and data transfer history of the datalogger, and the HOBO's serial number and its dates of usage (this later bit of information is to allow the tracking of the replacement of individual HOBO units as they fail).

Air velocity sampling: seasonal mode

These sampling periods usually last about two or three weeks and are used to "hunt" for airflow regions within a cave cross-section. Multiple anemometers are placed, on tripods or WKU's instrument lift system (see below), in the cross-section of interest. Once the anemometers have been in the field for a few weeks, data are analyzed and anemometers that show "different" airflow data are identified.

The anemometers are most easily set up on tripods. The tripods do not need to be heavy duty as the anemometers are not heavy. The only problem with tripods in general is they do not reach very high, so getting anemometers higher into a cave passage is problematic. The other commercially available alternative is a weather tower. These towers usually are bulky and need to be set in concrete. Both of these traits make these towers undesirable alternatives for mounting anemometers in cave cross-sections. To overcome this problem, the investigators contracted with WKU engineering staff to design and construct an "instrument lift system" capable of lifting anemometers (as well as other hardware) as high as ten meters up towards a cave cross-section's ceiling. The instrument lift system may be placed in suitable cave cross-sections and has a self-contained stabilization system, eliminating the need to mount the system in concrete or to send out guy wires that are attached to the cave floor. The system contains a motorized lift mechanism that can lift an instrument to any desired height. The instrument lift system was developed by the Department of Engineering at WKU.

In some cases, cables running between the anemometer heads and the datalogger may need to cross tourist trails. Such loose cables could be a tripping hazard if run directly across the trail. Therefore, in cross-sections containing a tourist trail with at least one anemometer on each side, two dataloggers should be used. The first datalogger controls the anemometer(s) on one side of the tourist trail, and the second datalogger controls the anemometer(s) on the other side of the trail. This arrangement keeps cabling out of the tourist trail.

Once all anemometers are in place, the locations of each anemometer should be mapped using the instrumentation provided by WKU. These mapping coordinates are documented on a site setup field form. Additional data noted on these field forms include date of setup and “as left” measurements from the anemometers. This practice insures that equipment is operating properly when technicians depart from the site.

Air velocity sampling: monitoring mode

The sensor setup concerns for monitoring mode are the same as those for seasonal mode. Multiple anemometers on multiple dataloggers may be necessary if tourist trail existence and cross-section heterogeneity in airflow warrant such an arrangement. These anemometers may be placed on either tripods or WKU’s instrument lift system. Also, field forms are provided for routine maintenance that should take place during monitoring mode, with such maintenance being primarily concerned with data transfer and replacement of depleted batteries with fresh batteries.

Data Management

Air temperature, relative humidity, and air velocity sampling generate two types of data: those data that are created by and stored directly into dataloggers and those data that are handwritten onto field forms. Our sampling approaches are such that the preponderance of our data is of the former type. Datalogger-created-and-stored data are free of transcription errors that can manifest themselves in hand-entered data. Collecting data in this way also streamlines data collection by minimizing sampler handling and data entry. The only data not datalogger-driven are biota existence data for seasonal at/rh sampling and methodological specific metadata such as who collected the data. Some data from routine maintenance visits are also hand-entered into a database, thereby allowing such things as site histories to be compiled by the database. Hand-entered data are minimal in quantity and may be quickly and easily added to the database via methodological specific data entry forms.

Overview of Database Design

Following the lead of the National Park Service (NPS) and the Inventory and Monitoring (I&M) Program, the CUPN-MACA Monitoring Program has adopted MS Access XP (2002) as its desktop database standard and ArcGIS as the GIS standard.

Rather than developing a single, integrated database system, CUPN-MACA relies upon modular, standalone project databases that share design standards based on the I&M Program's Natural Resource Database Template [NRDT (v 3.0)] with links to shared lookup tables housed in a centralized database. This and other long-term monitoring protocol databases developed by CUPN share certain design standards. This is important given the often unpredictable ways in which datasets may be aggregated and summarized. Each monitoring protocol database is developed using the following primary components:

1. *Common lookup tables* – Links to entire tables that reside in a centralized database, rather than storing redundant information in each database. These tables contain information that is not project-specific (e.g., lists of parks, personnel, and species).
2. *Core tables and fields based on CUPN-MACA and national templates* – These tables and fields are used to manage the information describing the “who, where and when” of project data. Core tables are distinguished from common lookup tables in that they reside in each individual project database and are populated locally. These core tables contain critical data fields that are standardized with regard to data types, field names, and domain ranges.
3. *Project-specific tables and fields* – The remainder of database objects can be considered project-specific, although there will typically be a large amount of overlap among projects. For example, a time field will require similar data types and domain values.

A noteworthy deviation from the NRDT for this and other cave-related protocols is the development of a “tlu_Cave_Locations” table. While this table's structure is nearly identical to the NRDT's tbl_locations, its functionality has changed in that it is a common lookup table shared among protocols, as opposed to being a core table within each protocol database. The decision to break out cave location information in this manner was largely due to its recognized sensitivity level. The project-specific data tables for this monitoring protocol database include:

Currently the Cave Meteorology Monitoring Protocol database is designed to hold three types of field data. These include: “seasonal” spatially distributed temperature and relative humidity data (Campbell data); long-term, automated temperature and relative humidity data (HOBO data); and air velocity within a cave cross section (Airflow data). Method specific tables are indicated within the table names. For example, table names beginning with “tbl_C_” contain Campbell data. While table names beginning with “tbl_AF” and “tbl_H” contain Airflow and Hobo data respectively. Refer to SOP # 6 “Data Management”, Appendix B for a complete list of tables, fields, and descriptions within the cave meteorology database.

Data Entry

Use of programmatic quality assurance checks has been incorporated into the data entry forms where possible. For example, look-up tables containing program specific data (e.g., caves and contacts) are utilized to greatly limit the possibility of entering incorrect values in these fields. It is anticipated that as testing and development of this database progresses, additional measures will be identified and incorporated into data entry forms.

Data entry mimics the order in which data are collected in the field. Specifically metadata gathered in the field (e.g., cave, date, and observers) are the first phase of data entry utilizing method specific data entry forms. The next phase of data entry is to import the digital file collected on the datalogger in the field. A command button is present on each of the data entry forms, which automates this task for the data entry technician. The data entry technician will be provided opportunity to review the file and cancel the operation if needed.

Data Verification and Validation

Data verification immediately follows data entry and involves checking the accuracy of the computerized records against the original source (hard copy datasheets), and identifying, correcting and documenting any errors. Data validation involves reviewing computerized data for range and/or logic errors. For instance, a cave temperature value of 58 degrees Celsius may have been accurately transcribed from the field datasheets but the value is not logical and most likely recorded in error. These are the kinds of errors, one hopes to purge from the dataset during the validation process. For this protocol data verification will typically be conducted by the individual entering the data. However, validation should be performed by the project leader; someone who has comprehensive knowledge of the dataset and expected values.

Some verification and validation procedures for this protocol have been developed (refer to SOP #6, Data Management). However, the data manager and project leader will develop and test additional measures prior to full implementation of the protocol.

Data Archival Procedures

This and other monitoring protocols will have variable long-term data archiving requirements. Modifications to protocols may require complete datasets to be archived before modifications are implemented. Archived datasets or subsets destined for long-term archiving will be saved in their native formats. To ensure the capability of accessing the data the application software will be maintained. If it is not possible to archive or support the application software, the data will be stored as ASCII text files.

Prior to significant changes of a dataset, a copy is stored with the appropriate version number. This allows for the tracking of changes over time. With proper controls and communication, versioning ensures that only the most current version is used in any analysis. Versioning of datasets is handled via a two digit numeric value (e.g., Cave_Air_v**1.0**_be.mdb). Once archived, an eight digit date value is also appended to the end of the file name (e.g., Cave_Air_v1.0_be_**20070312**.mdb). Frequent users of the data are notified of the updates, and provided with a copy of the most recent archived version as requested.

Tabular datasets destined for archiving will be stored locally within an object-oriented file structure established on the CUPN file server. Incremental or differential tape backups of all project databases on the server are regularly conducted. Backup copies of the data are maintained in a secure alternate location. Currently, GIS files are maintained and archived separately by the GIS specialist.

Analysis and Reporting

Data Analysis

The monitoring questions and subsequent analysis of the supporting data address issues related to status and trends in air velocity, air temperature, and relative humidity in cave spaces and on or adjacent to cave surfaces of interest. Magnitudes of and changes in status and trends of these parameters are likely to produce impacts on biotic and abiotic components of cave systems. Data collected through this protocol may be used to assess the impacts on cave meteorology of management activities, such as cave entrance modification, and variable disturbance from cave tours. The sampling design for air velocity provides an optimal anemometer location within a cross-section as well as the data collected through that anemometer. The sampling design for air temperature and relative humidity provides an assessment of spatial distribution of these parameters within a cave room along a surface of interest. These spatial data may be analyzed to generate the mean air temperature and relative humidity for the cave space sampled. Additionally, the standard deviations may be computed for the cave space, thereby providing an index for spatial heterogeneity in air temperature and relative humidity within the cave space. All data (air velocity, air temperature, and relative humidity) may be collected over multi-year scales. When collected over long-term (as well as short-term) time scales, these data may be used to evaluate the impacts of management actions upon air temperature and relative humidity (and impacts on air temperature and relative humidity could have subsequent impacts on biotic and abiotic cave components). Monitoring questions will be addressed using a combination of summary and descriptive statistics, graphic analysis, and multivariate comparative and correlative analysis.

The development of basic queries and summary reports in MS Access will be utilized to automate and thus streamline the data analysis and reporting workload, as appropriate. In consultation with the project leader, the data manager will develop queries (and accompanying summary reports) that will address basic statistical questions. It is anticipated the results of these queries will be relied upon heavily for annual reporting.

In instances where the statistical questions become increasingly complex, data will need to be exported out of the relational MS Access database to commercial off-the-shelf statistical packages for higher level statistical analyses (i.e. t-tests and ANOVA). In general, these data will be formatted based on parameters provided to the data manager via a make-table query in MS Access. The generated table will be exported in comma delimited ASCII text format for import into the appropriate statistical analysis software.

Reporting

There will be three main categories of reports produced from cave meteorology monitoring at MACA. The first is an annual status report. The second type of report will be used to summarize long-term trends and will become available after multiple years (~5) of monitoring have been completed. The third type of report is a project summary report for short-term projects. Annual status reports will address the same basic questions as long-term summary reports, but at different time scales. In cases where management has requested a specific condition assessment or sampling event and location, the project summary report will be generated to provide results, analysis, and interpretation of that effort.

In an effort to disseminate findings in a timely manner, annual reports should be completed by March 31 of the year following data collection. A brief (2-3 paragraphs) summary of sampling activities, preliminary results, and any public interest highlights that occurred during each federal fiscal year will be written by October 15 for inclusion in the CUPN-MACA Monitoring program's Annual Administrative Report. More extensive summary reports (long-term trend reports) should be completed every five years. Summary reports may be used in place of annual reports for the year in which the last data are collected.

Personnel Requirements and Training

Roles and Responsibilities

Implementation of this protocol requires an overall project leader and at least one 2-person project crew. The project leader oversees and directs project operations, including training of personnel. Each crew consists of one project crew leader and at least one project crew member. The project crew leader has site familiarity, cave meteorological sampling techniques expertise, and is responsible for team tasks. The project crew member has varied and less expertise, and is responsible for assisting the crew leader with data collection.

The project leader is the principal physical scientist for implementing this monitoring protocol and is supervised by the MACA Prototype coordinator. The project leader will be responsible for training, data collection, filing trip reports with the data manager, some data entry, data verification, data validation, data summary, analysis, and reporting. Trained NPS scientists will serve as crew leaders and will be responsible for preparation of supplies/equipment, conducting pre-sampling site-checks, some training, project crew oversight, data collection, data recording, post-sampling equipment inspection and storage, and some data entry. Crew members, will be responsible for assisting with pre-sampling site-checks, some data collection and some data entry. Data management will be shared responsibilities among the project leader and data manager. The data manager and project leader will develop automated data entry forms and database features as part of the quality assurance process. The data manager is ultimately responsible that adequate QA/QC procedures are built into the database management system. The data manager, project leader, and MACA Prototype coordinator are jointly responsible for ensuring data handling procedures are followed.

Qualifications and Training

An essential component for the collection of credible, high-quality data is well-trained and experienced project crew leaders. Therefore, new crew leaders should be thoroughly familiar with SOP #4a and SOP #4b, which address field sampling procedures, and should be given hands-on training by the project leader, or an experienced crew leader designated by the project leader, for each of the items detailed therein. Because of the time and effort required to fully train a crew leader, it is recommended that only permanent staff scientists be trained as crew leaders. The overall project leader should be a permanent staff member as well.

Special qualifications and training for crew members is not required because the tasks assigned to them can be easily taught and rehearsed in less than 1-hour during a pre-sampling “training and handling preparation” meeting held prior to a sampling *session* (SOP #1 “Training of Field Personnel, Checklist 1). Due to the need for underground travel and in environments with some surface relief, all project crew should be free of claustrophobia and relatively physically fit.

Operational Requirements

Field Schedule and Annual Workload

Field sampling for air temperature/relative humidity monitoring requires one two-person crew to service each cave space of interest. Cave spaces will be sampled on schedules appropriate to the specific intent of the sampling effort. Each cave space should be sampled one time per month. Transit times between the office and the cave space will vary from cave space to cave space. Sampling of the cave space will generally take between 1 ½ and 2 hours.

Field sampling for air velocity sampling requires one two-person crew for equipment setup and equipment disassembly, but a one-person crew can perform maintenance visits (although safety issues may warrant a two-person crew for maintenance visits as well). Seasonal sampling takes place four times per year, so there are four equipment-setups, four maintenance visits, and four equipment-disassemblies per year. While in monitoring mode (between seasonal disassembly and setup), there are typically one or more maintenance visits. Setup and disassembly of equipment take about two hours each while maintenance visits take about fifteen minutes. These times do not include transit times. An example calendar of events is shown in Table 3 (italicized events require a two-person crew, non-italicized events *require* a one-person crew although safety concerns may dictate that a two-person crew be used).

Table 3. Example schedule for air velocity sampling.

<i>Seasonal Sampling Periods</i>	Monitoring Periods
<i>January 1 – Setup 1</i> January 8 – Maintenance 1 <i>January 15 – Disassembly 1</i>	February 15 – Maintenance 2 March 15 – Maintenance 3
<i>April 1 – Setup 2</i> April 8 – Maintenance 4 <i>April 15 – Disassembly 2</i>	May 15 – Maintenance 5 June 15 – Maintenance 6
<i>July 1 – Setup 3</i> July 8 – Maintenance 7 <i>July 15 – Disassembly 3</i>	August 15 – Maintenance 8 September 15 – Maintenance 9
<i>October 1 – Setup 4</i> October 8 – Maintenance 10 <i>October 15 – Disassembly 4</i>	November 15 – Maintenance 11 December 15 – Maintenance 12

This at/rh/velocity sampling intensity and servicing schedule results in the following annual workloads (Table 4).

Table 4. Annual workload estimates for at/rh and air velocity sampling.

<i>Session Type</i>	<i>Number of People</i>	<i>Number of Sessions Per Year</i>	Session Duration
AT/RH Seasonal Sampling and HOBO Servicing	2	As many as 12	~ 2 hours + to-and-from transit time
Airflow Site Setup or Disassembly	2	8	~ 2 hours + to-and-from transit time
Airflow site maintenance	1 or 2	12	~15 minutes + to-and-from transit time

Ample time should be allotted in the sampling schedule to allow for datalogger and instrumentation calibration as necessary. Some of the instrumentation used requires no calibration (the Windsonic ultrasonic anemometer), but most of the equipment does require periodic calibration. Dataloggers and sensors should be calibrated per the manufacturer's recommendations.

Office-based work will require the following amount of time. For air temperature/relative humidity sampling, electronic entry of all field data for one cave space will take approximately 6-8 hours per year for a crew member to complete. For air velocity monitoring, electronic entry of all field data for one cave cross-section will also take approximately 6-8 hours per year for a crew member to complete.

The following time estimates apply to both air temperature/relative humidity and air velocity monitoring. Data verification, editing, validation, archival, and metadata procedures are estimated to require approximately 9 office-days per year (7 days for data manager and 2 days for project leader). With the aid of queries to automate the workload, data analysis is estimated to take approximately five office-days per year (3 days for project leader, and 1 day each for the data manager and another NPS scientist). Producing the annual status report is estimated to consume 5 office-days per year (4 days for project leader, and ½ day each for data manager and GIS specialist). Therefore, for either air temperature/relative humidity or air velocity monitoring, all data management, analysis, and reporting activities are estimated to involve a total of 21 office-days per year.

Facility and Equipment Needs

The nature of cave meteorological sampling work does not require special facilities beyond normal office space and equipment storage needs. Checklists 2, 3, and 4 in SOP #2 "Pre-Sampling" are lists of field equipment needs for one crew.

Startup and Monitoring Costs

Personnel expenses for field work are based on one crew of two people—an NPS scientist to oversee the entire sampling session (project leader) and/or act as crew leader, plus a transient individual to act as a crew member. As detailed above, cave meteorology monitoring is estimated to require a minimum total of 3 field-days (per cave space for air temperature/relative

humidity) and a minimum total of 5 field-days (per cross-section for air velocity monitoring) to implement. Field costs will vary somewhat from year to year based on the skill level and size of the crew. Data management-related personnel expenses will include staff time of student interns, the project leader, the data manager, and other NPS staff and is estimated to require a total of 8 office-days per cave space sampled.

There are no anticipated startup costs for implementing this protocol at MACA, since all items on the list of supplies and equipment (SOP #2 “Pre-Sampling”, Checklists 2, 3, and 4) have already been purchased. For a park that does not already have the necessary equipment, hardware requirements/vendors/2005 costs are listed below. Perennial supplies and equipment costs should be minimal, since the equipment that is needed is non-perishable and does not need to be replenished (with the exception of field notebooks and pens/pencils). The only significant perennial supplies and equipment costs are for equipment calibration and repair/replacement of malfunctioning equipment.

Listed below is the equipment necessary to conduct the sampling described in this protocol. There are three lists: one list of equipment that is used for both at/rh and air velocity sampling, one list for air temperature/relative humidity sampling, and one list for air velocity sampling.

Equipment List for Air Temperature / Relative Humidity and Air Velocity Sampling

One of each of the following parts is required for at/rh and wind velocity sampling. The parts listed below may be simultaneously used for both sets of parameters, so only one set is necessary for each park.

Description (Vendor / Part Number)	Price in US dollars
LoggerNet software (Campbell Scientific / LoggerNet)	\$545.00
CR10KD keypad for Campbell Scientific datalogger interface (Campbell Scientific / 17236)	\$280.00
SM4M storage module (Campbell Scientific / SM4M)	\$375.00
SC32B optically isolated RS232 interface (Campbell Scientific / 17229) .	\$80.00
SC532B RS232 to CS I/O interface (Campbell Scientific / 17029)	\$100.00
Wall charger for SC532A (Campbell Scientific / 15966)	\$16.00
Battery charger for CR10X batteries	
Mapping equipment (Western Kentucky University / contact prototype coordinator)	
Digital camera	

Equipment List for Air Temperature / Relative Humidity Sampling

The parts listed below are used only for air temperature / relative humidity sampling. These supplies either can not or should not be simultaneously used for air velocity sampling.

<u>(Quantity per park, if shown)</u>	<u>Description (Vendor / Part Number)</u>	<u>Price in US dollars</u>
(1)	Campbell Scientific CR10X datalogger	
	(Campbell Scientific / CR10X)	\$1250.00
(1)	Battery for CR10X datalogger	
(1)	Vaisala air temperature and relative humidity probe with user-specified cable length (Campbell Scientific / HMP45C)	\$520.00 + 0.55 / ft
	HOBO Pro RH/Temp datalogger (Onset / H08-032-08)	\$169.00
(1)	BoxCar Pro software with PC interface cable (Onset / BCP4.3-ON)	\$95.00
(1)	HOBO shuttle (Onset / H09-003-08)	\$159.00
	Replacement battery for HOBO Pro RH/Temp dataloggers	
	(Onset / HP-B)	\$12.00
	Replacement batteries for HOBO shuttle – the shuttle uses two batteries at a time (Onset / HRB-Temp)	\$19.00 for 10 singles
	~2m schedule 40 ½ inch PVC pipe (purchase locally)	About \$5
	Camera tripod (purchase locally)	About \$40
	Camera backpack or Pelican Case	
	Lasers	
	Rite in the Rain book with preprinted event field form on each page	

Equipment List for Air Velocity Sampling

The parts listed below are used only for air velocity sampling. These supplies either can not or should not be simultaneously used for air temperature and relative humidity sampling.

<u>(Quantity per park, if shown)</u>	<u>Description (Vendor / Part Number)</u>	<u>Price in US dollars</u>
	Campbell Scientific CR10X datalogger (Campbell Scientific / CR10X)	\$1250.00
(2 per CR10X datalogger)	Battery for CR10X datalogger	
	Windsonic Ultrasonic Anemometer - SDI-12 output with user-specified cable length (Campbell Scientific / 17370)	\$1385.00 + 0.47 / ft
	Camera backpack or Pelican case	
	Rite in the Rain book with preprinted event field form on each page	
	Hose clamps	
	Plumber's putty	
	Instrument lift system (Western Kentucky University / contact prototype coordinator)	
	Tripod	

Procedure for revising the Protocol and Archiving Previous Protocol Versions

No protocol can be expected to remain unchanged over the long term. The cave meteorology protocol is no exception. We anticipate the foundation, the logic and rationale of program design, to remain as written over the term of the program. However, there will come a time when program logistics, such as sample locations, methods, and reporting criteria may require updating. Careful documentation of changes to the protocol are essential when people, years from now, are examining data trends for example, to know exactly what conditions the data were gathered. All cave meteorology monitoring data will be entered into a project-specific MS Access database, which contains a field that denotes the protocol version under which the data were collected. Each protocol version will be properly archived to ensure future retrieval.

The rationale for dividing a sampling protocol into a Protocol Narrative with supporting SOPs is based on the following:

- The Protocol Narrative is a general overview of the protocol that gives the history and justification for performing the work as well as sampling methods. It does not contain all methodological details which are found in the accompanying SOPs. The Protocol Narrative is changed only if major revisions are necessary.
- The SOPs, in contrast, are specific detailed instructions for performing given tasks and are expected to be revised more frequently than the Protocol Narrative.
- When a SOP is revised, in most cases, it will not require modification to the Protocol Narrative, unless they affect the Narrative direction or rationale.
- All versions of the Protocol Narrative and SOPs will be archived in the MACA Prototype protocol library and referenced to the resulting Woodrat data.

Steps for changing the Protocol Narrative or SOPs are detailed in SOP #9 “Revising the Protocol”. The Protocol Narrative and each SOP contains a Revision History Log that will be filled out each time the Protocol Narrative or an SOP is changed.

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

References

- A Proposal for Designation of Mammoth Cave National Park as the Prototype Long-Term Ecological Monitoring Site for the Cave Biogeographic Category. 1993. Un-published document on file at Mammoth Cave National Park. 109 pp.
- Aley, Thomas, K. Castillon and J. Sagendorf. Strategy for Managing Alpha Radiation in Show-Caves to Protect Caves, Cave Employees, and Cave Businesses. Preprint. National Cave and Karst Management Symposium, Albany, New York. 2005.
- Carson, Bobby C. Summary and Findings of the Radon Daughter Monitoring Program at Mammoth Cave National Park, Kentucky. International conference: Radiation Hazards in Mining: Control, Measurement, and Medical Aspects. Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. New York, New York, edited by Manuel Gomez: 654-658. 1981.
- Fry, John and Johnathan Jernigan. CAM Protocol: Monitoring Atmospheric Conditions in Mammoth Cave. Unpublished project protocol document, Mammoth Cave, Kentucky. 2007.
- Indiana Bat Recovery Team. Agency Draft: Indiana Bat (*Myotis sodalis*) Revised Recovery Plan. Prepared for Region 3 U.S. Fish and Wildlife Service, Ft. Snelling, Minnesota. 1999.
- Jernigan, Johnathan. Mathematical Modeling of Convective Heat Transfer in Mammoth Cave. Master's thesis, Western Kentucky University, Bowling Green, Kentucky. 1997.
- Jernigan, Johnathan. An Analysis of Radon Data from Mammoth Cave. Unpublished project report, Mammoth Cave, Kentucky. 1999.
- Jernigan, Johnathan. Update to An Analysis of Radon Data from Mammoth Cave. Unpublished project report, Mammoth Cave, Kentucky. 2002.
- Olson, Rick. Ecological Restoration in the Natural Entrance Ecotone of Mammoth Cave With Emphasis on Endangered Species Habitat and Mitigation of Visitor Impact. Project Proposal (unpublished), Mammoth Cave, Kentucky. 1995.
- Olson, Rick. "This Old Cave: The Ecological Restoration of the Historic Entrance Ecotone of Mammoth Cave, and Mitigation of Visitor Impact." Proceedings of the Fifth Annual Mammoth Cave National Park Science Conference, Mammoth Cave, Kentucky. 1996.
- Smith, Ryan, R. Olson, B. Carson and J. Meiman. Radon Monitoring at mammoth Cave National Park: An Interim Report. Proceedings of the Sixth Annual Mammoth Cave National Park Science Conference. Mammoth Cave National Park and The Cave Research Foundation, July 31 – August 1, 1997, 99-111. 1997.

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 1: Training of Field Personnel

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

Implementation of this protocol requires an overall **project leader** and a minimum of one 2-person project crews. The project leader oversees and directs project operations, including training of personnel. Each crew consists of one **project crew leader** and at least one **project crew member**. The project crew leader has site familiarity, cave meteorological sampling techniques expertise, and is responsible for team tasks. The project crew member has varied and less expertise, and is responsible for assisting the crew leader with data collection.

An essential component for the collection of credible, high-quality cave meteorological data is well-trained and experienced project crew leaders. This cannot be overemphasized. Therefore, new crew leaders should be thoroughly familiar with SOP #4a, SOP #4b, and SOP #4c which deal with field sampling and should be given hands-on training by the project leader, or an experienced crew leader designated by the project leader, for each of the items detailed therein. The overall project leader should be a permanent staff member. Several crew leaders should be trained (and should participate in sampling on a regular basis) from among Mammoth Cave National Park (MACA) staff in case primary crew leaders are unavailable for particular sampling *trips*. Proper adherence to SOP #2 “Pre-Sampling” should serve to refresh and “recalibrate” the crew leaders’ abilities to prepare for sampling; locate sampling sites; and properly record the information—which ensures integrity of the data being collected.

Transient personnel (e.g., student interns, short-term or seasonal employees, volunteers, etc.) should serve as project crew members (i.e., field assistants). While review of SOP’s 4a, 4b, and 4c for crew members is encouraged, it is not essential because the tasks assigned to crew members can be easily taught and rehearsed in less than 1-hour during a pre-sampling “training for collection of air quality” meeting prior to completion of field work. In this meeting, the project leader (or designated crew leaders) also reviews member roles, steps in the sampling process, the particular safety Job Hazard Analyses, and two-way radio use. A checklist to assist the training and preparation meeting facilitator is provided (Checklist 1).

Checklist 1 – Generalized Logistical Checklist for Cave Meteorology Monitoring

- ☐ 1. Demonstrate how to launch and download HOBO dataloggers (see SOP #2 “Pre-Sampling” and SOP #5 “Post-Sampling”).
- ☐ 2. Demonstrate how to attach sensors to and operate Campbell Scientific’s CR10X dataloggers (see SOP #2 “Pre-Sampling,” SOP #4a “Seasonal Sampling and Monitoring of Air Temperature and Relative Humidity,” and SOP #4b “Seasonal Sampling and Monitoring of Cross-Sectional Air Velocity”).
- ☐ 3. Review roles of project crew leader and crew member(s) (see SOP #1 “Training of Field Personnel”).
- ☐ 4. Demonstrate knowledge of site setup procedures for air temperature/relative humidity and airflow sampling as appropriate (see SOP #4a “Seasonal Sampling and Monitoring of Air Temperature and Relative Humidity” and SOP #4b “Seasonal Sampling and Monitoring of Cross-Sectional Air Velocity”).
- ☐ 5. Review steps in the field sampling process for air temperature/relative humidity sampling and airflow sampling as appropriate (see SOP #4a “Seasonal Sampling and Monitoring of Air Temperature and Relative Humidity” and SOP #4b “Seasonal Sampling and Monitoring of Cross-Sectional Air Velocity”).
- ☐ 6. Review appropriate Job Hazard Analyses (JHA’s).
- ☐ 7. Demonstrate proper use of the park’s two-way radios (including radio call #’s).

Crew Leader’s Signature: _____

Date: _____

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 2: Pre-Sampling

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP gives procedures for:

- I. General sampling preparation
- II. Campbell CR10X dataloggers: wiring and programming instructions
- III. Launching HOBO dataloggers
- IV. Conducting pre-sampling accessibility checks of cave entrances
- V. A brief description of how cave meteorological monitoring should be scheduled at Mammoth Cave National Park (MACA)
- VI. How to organize supplies and equipment

In order to reduce lost time and perhaps lost data, pre-trip checklists are provided (Checklist 2, Checklist 3, and Checklist 4). All of the equipment and supplies listed in these checklists should be organized and made ready for each trip into the field, and copies of the appropriate field data form(s) (Appendix A through Appendix F) should be made. These SOP's describe tasks to be performed prior to, during, and after a sampling event. The crew leader must check each item on the pre-trip list the day before the event for final details (such as keys, road closures, batteries for lights/GPS units, etc). Finally, as the crew leader prepares to depart for the field, the list(s) should be checked again and reconciled against supplies and equipment being loaded up to assure nothing is being left behind.

General Preparation and Review

Procedures:

1. It is assumed that a required NPS research/collecting permit to conduct this monitoring project will be maintained and an original copy kept in the project leader's ("Principal Investigator") vertical files. Each crew should carry a photocopy of the permit while in the field. It is recommended that a state collecting permit also be obtained and maintained by the project leader.

2. Copies of field data forms from recent sampling event should be reviewed to identify any unique events or hazards that may be encountered. Trip reports are based on information recorded on field data forms, so it is imperative that they are clearly organized for ease of field note entry. Thus, uniform field data forms printed on “Rite-in-the-Rain” paper will be used by project crew leaders in an effort to standardize field data entries between sampling crews (Appendix B, Appendix C, Appendix E, and Appendix F).
3. Prior knowledge of sampling procedures and locations is essential for efficient and consistent sampling efforts. Therefore, project crew leaders and crew members should be trained and refreshed (SOP #1 “Training of Field Personnel”), particularly if new personnel join the sampling crews or if intervals between sampling events are greater than or equal to six months.
4. The air temperature/relative humidity probe should be connected to the datalogger’s wiring panel prior to the sampling event. Wiring instructions are found in the following section of this SOP. Additionally, the datalogger will need to be programmed. The appropriate program is also found in the following section. Similar requirements apply to the airflow sampling portion of the protocol.

Campbell CR10X dataloggers: wiring and programming instructions

Campbell Datalogger Wiring: Air Temperature and Relative Humidity

The following instructions provide wiring details for connecting the Vaisala HMP45C air temperature/relative humidity probe to the Campbell Scientific CR10X datalogger. The air temperature/relative humidity probe should be wired into the datalogger’s wiring panel using the probe’s six wires and two jumper wires (jumper wires are ~5 cm long pieces of signal wire). The probe should be connected to the wiring panel as follows.

- Red – SW 12V
- Yellow – 4H
- Blue – 5H
- White – 5L
- Black – G
- Shield – G
- Jumper 1 – 4L to 5L
- Jumper 2 – SW 12V CTRL to C1

Instructions for connecting mapping equipment to the datalogger will be provided when the authors are provided the mapping hardware.

Campbell Datalogger Wiring: Air Velocity

The Windsonic Ultrasonic Wind Sensor may be purchased from Campbell Scientific. The sensor must be purchased possessing a user-specified communication protocol. For the cave meteorology protocol, we recommend purchasing sensors using the SDI-12 communication protocol. The SDI-12 communication protocol allows the signal wires of multiple anemometers to be tied together. Each group of wires need only be plugged into the datalogger at one port.

For the cave meteorology protocol, the anemometers are tied together using a 4-wire phone line junction box, as detailed in subsequent text. The following instructions provide wiring details for connecting multiple anemometers to the Campbell Scientific CR10X datalogger. These instructions assume that the anemometers use the SDI-12 communication protocol. The general wiring sequence is:

- Connect the manufacturer-supplied communication cable to the anemometer head via a quick-connect at one of the cable's end.
- Attach a 4-line RJ11 phone adapter to the remaining end of the anemometer's communication cable.
- For each anemometer, plug the 4-line RJ11 into any of the five ports on the 4-wire phone line distribution box.
- Connect the 4-wire phone line distribution box to the Campbell datalogger.

More detailed instructions for anemometer connection to a datalogger follows.

1. Connect the anemometer head to the anemometer cabling via the manufacturer supplied quick-connect at the cabling's end.
2. Splice the anemometer cabling onto short length (about one decimeter) piece of 4-wire phone line with an RJ11 adapter at one end. Cable colors should be paired to one another (i.e. black wire from anemometer should be spliced onto black wire from 4-wire phone line).
3. The anemometer cabling should have four wires at its loose end. These wires should have about 3/8 inch of bare wire showing at the ends and these bare wires should be coated in solder. If the four wires from the anemometer are not stripped so that about 3/8 inch of bare wire is showing, strip the wires now.
 - a) Cut about one decimeter of 4-wire phone line from the end of a short length of phone line. The one-foot length of phone line should have at its uncut end an RJ11 adapter ("RJ11 adapter" is the name of the plug that gets connected into a phone jack).
 - b) Strip back about 1/2 inch of outer insulation from the cut end of the phone line.
 - c) Strip back about 3/8 inch of insulation from the ends of the 4 wires of the phone line.
 - d) Connect the wires from the short piece of phone line to the anemometer cabling. For each color of wire, pair like-colors to one another by twisting together the wires from the phone line and the anemometer. Solder these connections. Apply a few wraps of electrical tape around the bare wire of each connection.
 - e) Fold back the four joined wires and tape along the cabling with electrical tape to secure the connection.
4. Plug each anemometer's RJ11 adapter into one of the ports on the 4-wire phone line distribution box. Anemometers may be plugged into any port.
5. The 4-wire phone line distribution box has a 4-wire cable running from it. Attach these four wires to the Campbell datalogger.
 - a) Cut the RJ11 adapter off the distribution box's 4-wire cabling.
 - b) Strip the outer insulation from the box's cabling.
 - c) Strip the insulation from the four wires of the box's cabling.
 - d) For each of the four wires, twist and solder the ends (do not solder the ends to one another).
 - e) Each wire from the box's cabling should be connected into the CR10X as follows:

- Red (supplies power to the anemometers) – 12V
 - Green (signal) – C8
 - Black (ground) – G
 - White (ground) – G
6. If necessary, repeat for second datalogger and its anemometers.

Changing the SDI-12 Address of a Windsonic Ultrasonic Wind Sensor

For the SDI-12 communication protocol, each anemometer has an internally-stored identifier which is referred to as its SDI-12 address. These SDI-12 addresses are numeric identifiers from the list {0,1,2,3,4,5,6,7,8,9}. The default address of a new anemometer is zero. When the datalogger queries the anemometer for data, the anemometer sends an identifier along with its current wind speed and direction measurements. This type of communication is possible because each anemometer head contains its own processing chip. In order to set the SDI-12 address of an anemometer, the user must interface with the anemometer's processing chip. This interfacing is accomplished using a terminal emulator that is provided as part of Campbell Scientific's Loggernet software package. Instructions follow for interfacing with an anemometer.

Two sets of equivalent instructions are provided for changing the SDI-12 address of an anemometer. The first set was written by the protocol leads and the second set was written by Campbell Scientific staff. The first set of instructions assumes that the anemometer is connected to the datalogger as prescribed above (that is, with the anemometer's green signal wire connected to the C8 port on the datalogger). The second set was typed verbatim from the instruction manual. In this document, the second version is presented with a box around the text.

1. Before power is supplied to the datalogger, verify that the anemometer is properly wired to the datalogger. If not, correctly wire the anemometer to the datalogger.
2. Power the datalogger.
3. Connect the datalogger to the PC using Campbell Scientific's SC32B Optically Isolated RS-232 Interface. Two 9-pin serial cables are required for the connection. The first cable is used to connect the interface to the PC, and the second cable is used to connect the interface to the datalogger. The interface has two serial ports, and each is labeled to assure that the interface is properly connected. The interface port labeled as RS-232 should be paired with the RS-232 port on the PC, and the interface port labeled as CS I/O should be paired with the CS I/O port on the datalogger.
4. Launch Loggernet (version 2.1c is used in this protocol).
5. Click on the Connect button.
6. The software may or may not automatically begin communication with the datalogger. On the bottom-left portion of the Connect window is a graphic showing two wires either connected, trying to connect, or not connected. If the datalogger does not automatically connect, then the user must manually trigger the connection. In order to manually trigger the connection, look on the upper-left portion of the "Connect" window to find a list of possible dataloggers. Click on the CR10X datalogger and click on the Connect button below this list.
7. If the datalogger already contains a program that communicates with the anemometer, proceed to Step 11. Otherwise, proceed to the next step.
8. Once the PC has connected with the datalogger, the program may be sent to the datalogger. In the middle of the Connect window, there is a Program section. Clicking on the Send

button launches a navigation window in which the user may select the program to be transferred to the datalogger. Navigate to and select the appropriate program. Please note that users of this protocol may request that the most recent version of the datalogger program be sent to them. Contact the MACA Prototype Coordinator for more information.

9. The navigation window will close and a Caution window will appear warning the user that transferring the selected program to the datalogger will result in the replacement of the datalogger's current program with the selected program and the erasure of any data on the datalogger. Click OK to send the program to the datalogger.
10. When transfer is complete, a window will be launched telling the user that the transfer was successful. Close the window to return to Loggernet's Connect window.
11. Launch the terminal emulator by selecting Test|Terminal Emulator... from the Loggernet toolbar.
12. Click the Open Terminal button.
13. Click inside the terminal emulator window and repeatedly press the Enter key until the *-prompt is seen.
14. To activate communications with the anemometer, key 8X followed by the Enter key.
15. Key ?! to view the anemometer's current SDI-12 address.
16. Change the anemometer's SDI-12 address. Key the anemometer's current SDI-12 address. Follow that entry by keying A. And follow that entry by keying the anemometer's desired address. Follow this string with an apostrophe. That is, key aAb!, where a is the old SDI-12 address and b is the new SDI-12 address.
17. The previous step will cause Loggernet to terminate communication with the anemometer. To restart communication with the datalogger, key 8X and then press Enter.
18. Verify that the anemometer's SDI-12 address is correct by keying the command ?! .
19. Terminate the session by exiting communications with the anemometer. Key * to exit communications.
20. Close the Terminal Emulator window.
21. Click on Disconnect within the Connect window.
22. Disconnect the datalogger from the SC32B interface. The interface may remain connected to the PC.
23. Power down the datalogger.
24. Repeat as necessary for additional anemometers.
25. Close Loggernet.

*The following is typed verbatim from Campbell Scientific's
instruction manual for the
WindSonic Sonic Anemometer – Array Based Classic Dataloggers section.*

Changing the SDI-12 Address Using LoggerNet and a Datalogger

Up to ten WindSonic or other SDI-12 sensors can be connected to a single datalogger control port. Each SDI-12 device must have a unique SDI-12 address between 0 and 9. The factory set SDI-12 address for the WindSonic is 0. The WindSonic SDI-12 address is changed in software by issuing the aAb! Command, where a is the current address and b is the new address, to the WindSonic over the SDI-12 interface. The current address can be found by issuing the ?! command.

A computer running LoggerNet can be used to issue a valid SDI-12 command through the datalogger to the WindSonic. For a complete list of SDI-12 commands supported by the WindSonic, see Section 11 of the Gill Windsonic manual.

- Connect a single WindSonic to the datalogger using Control Port p as described in Section 4, and download a datalogger program that contains the SDI-12 Recorder (Instruction 104) instruction with valid entries for each parameter.
- In the LoggerNet Toolbar, navigate to and activate the Test|Terminal Emulator ... menu. The "Terminal Emulator" window will open. In the Select Device menu, located in the lower left hand side of the window, select the station.
- Click on the Open Terminal button. If communications between the datalogger and PC are successful, the red bar located in the upper left hand side of the window will turn green.
- Click inside the "Terminal Emulator" window and press the <enter> key until the datalogger responds with the "*" prompt.
- To activate the SDI-12 Transparent Mode, on Control Port p, enter pX and press the <enter> key. The datalogger will respond with "entering SDI-12". If any invalid SDI-12 command is issued, the datalogger will exit the SDI-12 Transparent Mode.
- To query the WindSonic for its current SDI-12 address, enter the command ?!. The WindSonic will respond with the current SDI-12 address.
- To change the SDI-12 address, enter the command aAb!; where a is the current address from the above step and b is the new address. The WindSonic will change its address and the datalogger will exit the SDI-12 Transparent Mode.
- To activate the SDI-12 Transparent Mode on Control Port p, enter pX and press the <enter> key. Verify the new SDI-12 address by entering the ?! command. The WindSonic will respond with the new address.
- To exit the SDI-12 Transparent Mode, enter *.

Campbell Datalogger Programs: Transfer from a PC to the Datalogger

The datalogger should also have the appropriate program uploaded to it. The program "tells" the datalogger that the at/rh sensor is attached and provides the functionality required for seasonal at/rh data collection. There are three ways to get a program into a CR10X datalogger: transfer from a PC, transfer from the storage module, and manual, line-by-line entry into the datalogger.

The easiest way to get the program into the datalogger is transfer from a PC, so this is the method recommended.

To attach the datalogger to a PC and transfer the program from the PC to the datalogger, the following steps should be executed.

1. Before power is supplied to the datalogger, verify that the datalogger is properly wired. If the datalogger is not properly wired, correctly wire the at/rh probe to the datalogger.
2. Power the datalogger.
3. Connect the datalogger to the PC using Campbell Scientific's SC32B Optically Isolated RS-232 Interface. Two 9-pin serial cables are required for the connection. The first cable is used to connect the interface to the PC, and the second cable is used to connect the interface to the datalogger. The interface has two serial ports, and each is labeled to assure that the interface is properly connected. The interface port labeled as RS-232 should be paired with the RS-232 port on the PC, and the interface port labeled as CS I/O should be paired with the CS I/O port on the datalogger.
4. Launch Loggernet (version 2.1c is used in this protocol).
5. Click on the Connect button.
6. The software may or may not automatically begin communication with the datalogger. On the bottom-left portion of the Connect window is a graphic showing two wires either connected, trying to connect, or not connected. If the datalogger does not automatically connect, then the user must manually trigger the connection. In order to manually trigger the connection, look on the upper-left portion of the "Connect" window to find a list of possible dataloggers. Click on the CR10X datalogger and click on the Connect button below this list.
7. Once the PC has connected with the datalogger, the program may be sent to the datalogger. In the middle of the Connect window, there is a Program section. Clicking on the Send button launches a navigation window in which the user may select the program to be transferred to the datalogger. Navigate to and select the appropriate program. Please note that users of this protocol may request that the most recent version of the datalogger program be sent to them. Contact the MACA Prototype Coordinator for more information.
8. The navigation window will close and a Caution window will appear warning the user that transferring the selected program to the datalogger will result in the replacement of the datalogger's current program with the selected program and the erasure of any data on the datalogger. Click OK to send the program to the datalogger.
9. When transfer is complete, a window will be launched telling the user that the transfer was successful. Close the window to return to Loggernet's Connect window.
10. Click on Disconnect within the Connect window.
11. Disconnect the datalogger from the SC32B interface. The interface may remain connected to the PC.
12. Power down the datalogger.
13. Close Loggernet.

The datalogger will retain the program even after it has been powered down. So, reinstalling the program will be necessary only if the program needs to be updated, or, through extreme circumstances, the program is altered or deleted from the datalogger.

The CR10X program used to collect seasonal at/rh data follows.

```
;{CR10X}
;Cumberland Piedmont Network
;Air Temperature and relative humidity seasonal sampling
;Last modified: 3 November 2005
;Current version: v1.01
;Modification from previous version (v1.00): Changed memory locations of variables so that cave code and ;landmark are in locations 1 and 2,
;respectively. Also modified some comments.
;Modified by: Johnathan Jernigan
;Contact info: Physical scientist, Mammoth Cave National Park, PO Box 7, Mammoth Cave, KY 42259
;      270-758-2146, johnathan_jernigan@nps.gov
;
;Please note: as of this writing, distance and azimuth/elevation devices are not included in the program as the author has not received the
;hardware from Western Kentucky University's engineering department. Upon receipt of this equipment, the program will be modified to include
;these devices.
;
;
;
*Table 1 Program
01: 1      Execution Interval (seconds)

;Assign CaveCode and Landmark values, respectively. Default program values are zero, but these values may be altered and a datalogger with
;this program will retain updated values even when the datalogger has been powered
;down. To reset to default values, either manually adjust the values or reload the program from a PC or storage module.

1: Z=F x 10^n (P30)
1: 0      F
2: 0      n, Exponent of 10
3: 1      Z Loc [ CaveCode ]

2: Z=F x 10^n (P30)
1: 0      F
2: 0      n, Exponent of 10
3: 2      Z Loc [ Landmark ]

;Air temperature/relative humidity sensor instructions

;Initiate air sampling event by identifying air temperature/relative humidity sensor

3: Do (P86)
1: 41      Set Port 1 High

4: Excitation with Delay (P22)
1: 1      Ex Channel
2: 0      Delay W/Ex (0.01 sec units)
3: 15      Delay After Ex (0.01 sec units)
4: 0      mV Excitation

5: Volt (Diff) (P2)
1: 1      Reps
2: 5      2500 mV Slow Range
3: 4      DIFF Channel
4: 3      Loc [ VaisTemp ]
5: 0.1     Mult
6: -40     Offset

6: Volt (Diff) (P2)
1: 1      Reps
2: 5      2500 mV Slow Range
3: 5      DIFF Channel
4: 4      Loc [ VaisRelH ]
5: 0.1     Mult
6: 0      Offset

7: Do (P86)
1: 51      Set Port 1 Low

;Flag data as valid using flag 1
```

```

8: Timer (P26)
1: 5    Loc [ FlagTime ]

9: If Flag/Port (P91)
1: 11    Do if Flag 1 is High
2: 30    Then Do

    10: If (X<=>F) (P89)
    1: 5    X Loc [ FlagTime ]
    2: 4    <
    3: 1    F
    4: 30    Then Do

        11: Z=Z+1 (P32)
        1: 6    Z Loc [ Loc_ID ]

    12: End (P95)

    13: If (X<=>F) (P89)
    1: 5    X Loc [ FlagTime ]
    2: 3    >=
    3: 36    F
    4: 30    Then Do

        14: Timer (P26)
        1: 0    Reset Timer

        15: Z=F x 10^n (P30)
        1: 0    F
        2: 0    n, Exponent of 10
        3: 7    Z Loc [ Flag1 ]

        16: If (X<=>F) (P89)
        1: 5    X Loc [ FlagTime ]
        2: 3    >=
        3: 36    F
        4: 21    Set Flag 1 Low

    17: Else (P94)

        18: Z=F x 10^n (P30)
        1: 1    F
        2: 0    n, Exponent of 10
        3: 7    Z Loc [ Flag1 ]

        19: If (X<=>F) (P89)
        1: 5    X Loc [ FlagTime ]
        2: 3    >=
        3: 0    F
        4: 11    Set Flag 1 High

    20: End (P95)

21: Else (P94)

    22: Timer (P26)
    1: 0    Reset Timer

    23: Z=F x 10^n (P30)
    1: 0    F
    2: 0    n, Exponent of 10
    3: 7    Z Loc [ Flag1 ]

24: End (P95)

;Write output to final storage
;Data output is
;program id,cavecode,landmarkid,year,day,hour/minute,seconds,dataflag,plotnumber(loc_id),vaistemp,vaisrh

25: If time is (P92)

```

```

1: 0  -- Minutes (Seconds --) into a
2: 5   Interval (same units as above)
3: 10  Set Output Flag High (Flag 0)

26: Set Active Storage Area (P80)
1: 1   Final Storage Area 1
2: 101 Array ID

27: Sample (P70)
1: 1   Reps
2: 1   Loc [ CaveCode ]

28: Sample (P70)
1: 1   Reps
2: 2   Loc [ Landmark ]

29: Real Time (P77)
1: 1111 Year,Day,Hour/Minute,Seconds (midnight = 0000)

30: Minimum (P74)
1: 1   Reps
2: 0   Value Only
3: 7   Loc [ Flag1 ]

31: Sample (P70)
1: 1   Reps
2: 6   Loc [ Loc_ID ]

32: Average (P71)
1: 1   Reps
2: 3   Loc [ VaisTemp ]

33: Average (P71)
1: 1   Reps
2: 4   Loc [ VaisRelH ]

*Table 2 Program
02: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines

End Program

```

The CR10X program used to collect Datalogger 1 air velocity follows.

```

;{CR10X}
;Cumberland Piedmont Network
;Air velocity sampling - Datalogger 1 connected to SDI-12 addresses 0,1,and 2
;Last modified: 20 December 2005
;Current version: v1.00
;Modification from previous version (v ): N/A
;Original program written by: Johnathan Jernigan
;Contact info: Physical scientist, Mammoth Cave National Park, PO Box 7, Mammoth Cave, KY 42259
;                270-758-2146, johnathan_jernigan@nps.gov
;Modified by: N/A
;Contact info: N/A
;
;{CR10X}
;
*Table 1 Program
01: 300 Execution Interval (seconds)

;Assign values for cave id, cross-section id, and monitoring status
1: Z=F x 10^n (P30)
1: 0.0 F
2: 00 n, Exponent of 10
3: 1 Z Loc [ caveid ]

```

```

2: Z=F x 10^n (P30)
1: 0.0    F
2: 00     n, Exponent of 10
3: 2      Z Loc [ xsecid  ]

3: Z=F x 10^n (P30)
1: 0.0    F
2: 00     n, Exponent of 10
3: 3      Z Loc [ monstat  ]

;Monitor datalogger's battery voltage
4: Batt Voltage (P10)
1: 4      Loc [ battvolt  ]

;Set program to use three anemometers
5: SDI-12 Recorder (P105)
1: 0      SDI-12 Address
2: 0      Start Measurement (aM!)
3: 8      Port
4: 5      Loc [ winddir0  ]
5: 1.0    Mult
6: 0.0    Offset

6: SDI-12 Recorder (P105)
1: 1      SDI-12 Address
2: 0      Start Measurement (aM!)
3: 8      Port
4: 9      Loc [ winddir1  ]
5: 1.0    Mult
6: 0.0    Offset

7: SDI-12 Recorder (P105)
1: 2      SDI-12 Address
2: 0      Start Measurement (aM!)
3: 8      Port
4: 13     Loc [ winddir2  ]
5: 1.0    Mult
6: 0.0    Offset

; Following instruction has loop count equal to the number of windsonics attached
8: Beginning of Loop (P87)
1: 0      Delay
2: 3      Loop Count

; Following instruction always has step equal to four (corresponds to the input locations, i.e. direction, speed, diagnostic, and sample size in mean
; calculation
9: Step Loop Index (P90)
1: 4      Step

10: If (X<=>F) (P89)
1: 5      -- X Loc [ winddir0  ]
2: 4      <
3: -99990 F
4: 30     Then Do

11: Block Move (P54)
1: 2      No. of Values
2: 5      -- First Source Loc [ winddir0  ]
3: 1      Source Step
4: 6      -- First Destination Loc [ windspd0  ]
5: 1      Destination Step

12: End (P95)

13: End (P95)

;Write output to Final Storage
14: Do (P86)
1: 10     Set Output Flag High (Flag 0)

```

15: Set Active Storage Area (P80)
1: 1 Final Storage Area 1
2: 210 Array ID

16: Sample (P70)
1: 1 Reps
2: 1 Loc [caveid]

17: Sample (P70)
1: 1 Reps
2: 2 Loc [xsecid]

18: Real Time (P77)
1: 1220 Year,Day,Hour/Minute (midnight = 2400) ;

19: Maximum (P73)
1: 1 Reps
2: 0 Value Only
3: 3 Loc [monstat]

20: Minimum (P74)
1: 1 Reps
2: 0 Value Only
3: 4 Loc [battvolt]

21: If (X<=>F) (P89)
1: 7 X Loc [winddia0]
2: 2 $\diamond$
3: 0 F
4: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

22: Wind Vector (P69)
1: 1 Reps
2: 0 Samples per Sub-Interval
3: 0 S, theta(1), sigma(theta(1)) with polar sensor
4: 6 Wind Speed/East Loc [windspd0]
5: 5 Wind Direction/North Loc [winddir0]

23: Z=F x 10^n (P30)
1: 1 F
2: 0 n, Exponent of 10
3: 8 Z Loc [samples0]

24: Totalize (P72)
1: 1 Reps
2: 8 Loc [samples0]

25: If (X<=>F) (P89)
1: 11 X Loc [winddia1]
2: 2 $\diamond$
3: 0 F
4: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

26: Wind Vector (P69)
1: 1 Reps
2: 0 Samples per Sub-Interval
3: 0 S, theta(1), sigma(theta(1)) with polar sensor
4: 10 Wind Speed/East Loc [windspd1]
5: 9 Wind Direction/North Loc [winddir1]

27: Z=F x 10^n (P30)
1: 1 F
2: 0 n, Exponent of 10
3: 12 Z Loc [samples1]

28: Totalize (P72)
1: 1 Reps
2: 12 Loc [samples1]

29: If (X<=>F) (P89)

```

1: 15    X Loc [ winddia2 ]
2: 2     <>
3: 0     F
4: 19    Set Intermed. Proc. Disable Flag High (Flag 9)

30: Wind Vector (P69)
1: 1     Reps
2: 0     Samples per Sub-Interval
3: 0     S, theta(1), sigma(theta(1)) with polar sensor
4: 14    Wind Speed/East Loc [ windspd2 ]
5: 13    Wind Direction/North Loc [ winddir2 ]

31: Z=F x 10^n (P30)
1: 1     F
2: 0     n, Exponent of 10
3: 16    Z Loc [ samples2 ]

32: Totalize (P72)
1: 1     Reps
2: 16    Loc [ samples2 ]

33: Do (P86)
1: 29    Set Intermed. Proc. Disable Flag Low (Flag 9)

*Table 2 Program
02: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines

End Program

```

The CR10X program used to collect Datalogger 2 air velocity follows.

```

;{CR10X}
;Cumberland Piedmont Network
;Air velocity sampling - Datalogger 2 connected to SDI-12 addresses 3,4,and 5
;Last modified: 20 December 2005
;Current version: v1.00
;Modification from previous version (v ): N/A
;Original program written by: Johnathan Jernigan
;Contact info: Physical scientist, Mammoth Cave National Park, PO Box 7, Mammoth Cave, KY 42259
;                270-758-2146, johnathan_jernigan@nps.gov
;Modified by: N/A
;Contact info: N/A
;
;{CR10X}
;
*Table 1 Program
01: 300    Execution Interval (seconds)

;Assign values for cave id, cross-section id, and monitoring status
1: Z=F x 10^n (P30)
1: 0.0    F
2: 00     n, Exponent of 10
3: 1      Z Loc [ caveid ]

2: Z=F x 10^n (P30)
1: 0.0    F
2: 00     n, Exponent of 10
3: 2      Z Loc [ xsecid ]

3: Z=F x 10^n (P30)
1: 0.0    F
2: 00     n, Exponent of 10
3: 3      Z Loc [ monstat ]

;Monitor datalogger's battery voltage

```

```

4: Batt Voltage (P10)
1: 4    Loc [ battvolt ]

;Set program to use three anemometers
5: SDI-12 Recorder (P105)
1: 3    SDI-12 Address
2: 0    Start Measurement (aM!)
3: 8    Port
4: 5    Loc [ winddir3 ]
5: 1.0  Mult
6: 0.0  Offset

6: SDI-12 Recorder (P105)
1: 4    SDI-12 Address
2: 0    Start Measurement (aM!)
3: 8    Port
4: 9    Loc [ winddir4 ]
5: 1.0  Mult
6: 0.0  Offset

7: SDI-12 Recorder (P105)
1: 5    SDI-12 Address
2: 0    Start Measurement (aM!)
3: 8    Port
4: 13   Loc [ winddir5 ]
5: 1.0  Mult
6: 0.0  Offset

; Following instruction has loop count equal to the number of windsonics attached
8: Beginning of Loop (P87)
1: 0    Delay
2: 3    Loop Count

; Following instruction always has step equal to four (corresponds to the input locations, i.e. direction, speed, diagnostic, and sample size in mean calculation
9: Step Loop Index (P90)
1: 4    Step

10: If (X<=>F) (P89)
1: 5    -- X Loc [ winddir3 ]
2: 4    <
3: -99990 F
4: 30   Then Do

    11: Block Move (P54)
    1: 2    No. of Values
    2: 5    -- First Source Loc [ winddir3 ]
    3: 1    Source Step
    4: 6    -- First Destination Loc [ windspd3 ]
    5: 1    Destination Step

12: End (P95)

13: End (P95)

;Write output to Final Storage
14: Do (P86)
1: 10   Set Output Flag High (Flag 0)

15: Set Active Storage Area (P80)
1: 1    Final Storage Area 1
2: 345  Array ID

16: Sample (P70)
1: 1    Reps
2: 1    Loc [ caveid ]

17: Sample (P70)
1: 1    Reps
2: 2    Loc [ xsecid ]

```

18: Real Time (P77)
1: 1220 Year,Day,Hour/Minute (midnight = 2400) ;

19: Maximum (P73)
1: 1 Reps
2: 0 Value Only
3: 3 Loc [monstat]

20: Minimum (P74)
1: 1 Reps
2: 0 Value Only
3: 4 Loc [battvolt]

21: If (X<=>F) (P89)
1: 7 X Loc [winddia3]
2: 2 <>
3: 0 F
4: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

22: Wind Vector (P69)
1: 1 Reps
2: 0 Samples per Sub-Interval
3: 0 S, theta(1), sigma(theta(1)) with polar sensor
4: 6 Wind Speed/East Loc [windspd3]
5: 5 Wind Direction/North Loc [winddir3]

23: Z=F x 10^n (P30)
1: 1 F
2: 0 n, Exponent of 10
3: 8 Z Loc [samples3]

24: Totalize (P72)
1: 1 Reps
2: 8 Loc [samples3]

25: If (X<=>F) (P89)
1: 11 X Loc [winddia4]
2: 2 <>
3: 0 F
4: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

26: Wind Vector (P69)
1: 1 Reps
2: 0 Samples per Sub-Interval
3: 0 S, theta(1), sigma(theta(1)) with polar sensor
4: 10 Wind Speed/East Loc [windspd4]
5: 9 Wind Direction/North Loc [winddir4]

27: Z=F x 10^n (P30)
1: 1 F
2: 0 n, Exponent of 10
3: 12 Z Loc [samples4]

28: Totalize (P72)
1: 1 Reps
2: 12 Loc [samples4]

29: If (X<=>F) (P89)
1: 15 X Loc [winddia5]
2: 2 <>
3: 0 F
4: 19 Set Intermed. Proc. Disable Flag High (Flag 9)

30: Wind Vector (P69)
1: 1 Reps
2: 0 Samples per Sub-Interval
3: 0 S, theta(1), sigma(theta(1)) with polar sensor
4: 14 Wind Speed/East Loc [windspd5]
5: 13 Wind Direction/North Loc [winddir5]

```

31: Z=F x 10^n (P30)
1: 1      F
2: 0      n, Exponent of 10
3: 16     Z Loc [ samples5 ]

32: Totalize (P72)
1: 1      Repts
2: 16     Loc [ samples5 ]

33: Do (P86)
1: 29     Set Intermed. Proc. Disable Flag Low (Flag 9)

*Table 2 Program
02: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines

End Program

```

Launching HOBO Dataloggers

New HOBO Pro RH/Temp dataloggers will have batteries installed in them, but the datalogger will not be collecting data. To begin the data collection process, the datalogger should be connected to a PC from which BoxCar Pro (version 4.0 is used in this protocol) may be used to initiate data collection. Dataloggers that have previously been used may still be collecting data. Launching these dataloggers will cause data stored in the datalogger to be erased and result in the datalogger operating under the newly defined execution interval. To launch or re-launch a HOBO Pro RH/Temp datalogger, the following sequence should be used.

1. Unscrew the cover from the serial port access on the top of the HOBO datalogger.
2. Attach the datalogger to your PC. This step requires an interface cable so that the datalogger can communicate with the PC. The cable (part number CABLE-HOBO-SHTL) has a stereo jack at one end and a 9-pin serial connector at the other. First, plug the cable's 9-pin connector to a PC, and then connect the cable's stereo jack into the HOBO datalogger.
3. At the end of Step 11, the clock within the HOBO datalogger will be set to match the time on the PC to which it is attached. The datalogger's time needs to be Local Standard Time (LST). If the PC time is Local Daylight Time (LDT), the datalogger will be set to LDT at the end of Step 11. To avoid the datalogger's being set to LDT, verify that the PC is set to LST. If not, reset the PC clock to LST.
4. Launch BoxCar Pro.
5. Within the Logger menu, click on Launch... .
6. Within the Launch window, several options should be adjusted. The user may type in the description box an appropriate description of the datalogger. Recommended information is cave and cave room where the datalogger will be placed. The serial number of the datalogger should remain part of the datalogger description.
7. In the Interval(Duration) box, the user may select the length of time between data collection events. Select fifteen minutes from the pick list.
8. Verify that the datalogger's battery is fully charged. The indicator meter labeled Battery should be near 100%. We recommend that the battery be at least 90%. If not, replace the battery by disconnecting the datalogger from the PC (click Cancel in the Launch window and disconnect the cable from the datalogger, then remove the back from the datalogger and replace the battery). If the battery was replaced, restart at Step 1.

9. View the list of Current Enabled Channel #(s). Channels 1, 2, and 3 should be enabled. If not, click the Enable/Disable Channels button and enable all channels.
10. BoxCar Pro provides the user the option of delaying the collection of data until a date/time that is user-set. Do not select Delayed Start.
11. Click Start to launch the datalogger.
12. Two windows will be sequentially launched. The first window discusses the Enable/Disable Channels options. Click Yes to continue. The second window alerts the user that any data currently on the datalogger will be deleted. Click Yes to continue.
13. Remove the cable from the datalogger. Look into the datalogger port from which this cable was removed. A flashing, red LED should be visible. If the LED is not flashing, then the datalogger was not properly launched. In the event that the launch was unsuccessful, restart at Step 1 and try once more to launch the datalogger. If the second attempt is unsuccessful, assume that the datalogger is malfunctioning and, restarting at Step 1, try a new datalogger.
14. Replace the cover to the serial port access on the top of the HOBO datalogger.
15. Close BoxCar Pro.

Accessibility Check of Sampling Caves

1. A day or two before the scheduled sampling event, a project crew leader should obtain a hard copy of the **map** (i.e., from the project leader's file cabinet in the office, or print a new copy from the "Images" subfolder in the cave meteorology project folder on the shared drive on write-in-the-rain paper) with the appropriate cave locations and cave numbers. Also, obtain a hard copy of the appropriate **cave locations field list** (i.e., from the project leader's file cabinet in the office, or print a new copy from the "Docs" subfolder in the cave meteorology project folder on the shared network drive on write-in-the-rain paper) with written directions to the vehicle access parking location and to each cave from the vehicle, and geographic coordinates in Universal Transverse Mercator (UTM), utilizing the North American Datum 1983 (NAD83) projection, for parking and cave entrance locations. Review map and cave locations field list, and become familiar with route and directions to each cave prior to departing for the field.
2. The GIS specialist will download the most current geographic coordinates for each cave entrance scheduled for sampling into the GPS unit to be utilized by the respective field crews. *Note:* It is the responsibility of the project crew leader to schedule this task with the GIS specialist in advance and provide the GPS unit to the GIS specialist. If the waypoints have not been erased from the GPS unit since the last time the cave entrances were visited, simply confirm that the waypoint for each cave is there. *Note:* sampling cave waypoints can be stored on GPS units between sampling events. However, if caves are added or removed from the list of sampling caves for monitoring, the waypoint list must be updated and unneeded cave entrance location information should be erased from the GPS unit.
3. Following the written directions in the appropriate cave locations field list (and GPS unit if necessary), the crew leader and/or a crew member should drive a field vehicle to the designated parking spot (point on a road that is closest to the first cave entrance). Safely park the vehicle and locate the cave entrance on foot using the "Navigate" or "Go To" feature on the GPS unit (see operations manual for unit) in conjunction with the written directions and the map.

4. Confirm the correct entrance has been found by locating the permanent numbered brass marker (“cap”) anchored to a rock in the entrance, and/or the cave entrance description information. *Note:* presently, not all of Mammoth Cave National Park’s cave entrances have been permanently marked and many parks may not use such a marking system. The current permanent mark status for each cave should be noted on the cave locations field list.
5. Visually inspect cave entrance for new hazards (e.g., recent entrance collapse, unstable rocks in entrance, tree blocking entrance, flooding, ice in entrance, access road blocked or impassible, etc.). Make written notes regarding any such hazards and initial recommendations for later discussion with the project leader.
6. Continue as above to the second cave on the route until all cave entrances have been located. *Note:* it is not necessary to conduct a pre-sampling check of any “managed” cave entrances that receive daily visitation since all hazards will be reported by other NPS staff and resolved quickly.
7. Immediately give a copy of any written notes that may impact sampling session logistics to the project leader and discuss options with the project leader.
8. Based on outcomes of the discussion in procedure #7, adjustments [e.g., the sampling route (order), number of caves to sample, which caves to sample] will be made and a new cave locations field list (i.e., ordered route list) will be produced (on write-in-the-rain paper), necessary changes to the GPS waypoint list will be made, and the GPS unit and hardcopies will be placed with the rest of the supplies/equipment, assembled for the ensuing sampling session. *Note:* Caves on the cave locations field list should be arranged according to the order they will be encountered following the most time-efficient route.

Scheduling Field Work

Suggested field sampling schedules for air temperature/relative humidity sampling and air velocity sampling are included in the narrative of this protocol.

Organizing Supplies and Equipment

The crew leader should check each item on the supplies and equipment checklist (Checklists 2 through 4) to organize and make everything ready one day in advance of a sampling *session*. This allows time to make needed repairs, check batteries and purchase supplies, if necessary. The following is a list of field supplies and equipment needs for one sampling crew, along with a pre-trip logistical checklist. *Note:* most equipment maintenance and repair/replacement is routinely performed as a post-sampling task—this check serves as an assurance of current readiness.

Checklist 2 – Generalized Logistical Checklist for Cave Meteorology Monitoring

- ☐ 1. Schedule monitoring crews with caves and ordered routes in advance.
- ☐ 2. Reserve appropriate number and type of vehicles in advance.
- ☐ 3. Go through supplies/equipment checklist.
- ☐ 4. Check all appropriate equipment for battery (including two-way radios) condition—replace as needed.
- ☐ 5. Use a voltmeter to verify that the datalogger's battery is at least 12.7 volts. For air velocity sampling, the datalogger battery should be fully charged to about 13.1 volts.
- ☐ 6. Verify that wires from sensor(s) are securely attached to the datalogger's wiring panel.
- ☐ 7. Power on the datalogger to verify its proper operation.
- ☐ 8. Verify that the datalogger contains the proper program by scrolling through intermediate data (*6 mode) to confirm that memory locations contain the appropriate data. This step also verifies that sensors are properly connected to the datalogger.
- ☐ 9. Power down datalogger and pack equipment for transport to the field.
- ☐ 10. Verify that the datalogger date and time are correct (*5 mode).
- ☐ 11. Pre-sampling "cave-check" to locate and visually inspect each remote cave entrance.
- ☐ 12. Fill out Cave Entrance Request Form for all non-artificially lighted caves and file one copy with Ranger Division---Project leader keeps originals in file.
- ☐ 13. Obtain keys to cave gates/doors and road gates (*list will be provided here, but it is hidden in this protocol for security purposes*).
- ☐ 14. Perform general pre-trip vehicle inspection (check: first aid kit, fuel level, oil level, tires, spare tire and changing equipment, lights, and wipers).
- ☐ 15. Establish surface watch.
- ☐ 16. Sign out crew with destination, vehicle, and approximate return time on dry erase board in office.
- ☐ 17. Obtain copy of current NPS research/collecting permit from project leader, one for each field crew.

Crew Leader's Signature: _____

Date: _____

**Checklist 3 - Air Temperature and Relative Humidity Seasonal Sampling
Supplies/Equipment**

(Number Required)	Description
☐ (1)	Spiral rite-in-the-rain notebook for the plot collateral data
☐ (1)	Pelican case or backpack that contains the following four items
☐ (1)	Programmed Campbell Scientific CR10X datalogger
☐ (1)	Charged 12-volt battery
☐ (1)	Power cable for connecting Campbell datalogger to 12-volt battery
☐ (1)	Vaisala air temperature / relative humidity probe (attached via communication cable)
☐ (1)	~2m long ½" PVC pipe for attaching the air temperature / relative humidity probe
☐ (1)	Surveying equipment
☐ (1)	Camera tripod
☐ (1)	Two (2) lasers, each with fresh batteries
☐ (1)	Male-to-double female 9-pin serial cable
☐ (1)	~2m male-to-female 9-pin serial cable
☐ (1)	Campbell Scientific's keypad interface
☐ (1)	Campbell Scientific's SM4M storage module
☐ (1)	Roll of electrical tape
☐ (1)	Pencils or pens as needed
☐ (1)	Set of extra batteries for each laser
☐ (1)	Backpack and/or "fanny" pack to hold equipment
☐ (2)	Pair of work gloves
☐ (2)	Helmets with lights
☐ (2)	Handheld flashlights for backup
☐ (~10)	Extra AA batteries for lights and GPS unit
☐ (1)	Hard copy of map with cave locations (on write-in-the-rain paper)
☐ (1)	GPS unit with all cave entrance waypoints pre-programmed
☐ (1)	Two-way radio (operational and fully charged)
☐ (1)	First Aid kit
Crew Leader's Signature: _____ Date: _____	

Checklist 4 – Air Velocity Sampling Supplies/Equipment

(Number Required)	Description
☐ (1)	Spiral rite-in-the-rain notebook for site notes
☐ (1)	Digital camera for photography of site at time of setup
☐ (1)	Pelican case that contains the following five items
☐ (1)	Programmed Campbell Scientific CR10X datalogger
☐ (1)	Charged 12-volt battery
☐ (1)	Power cable for connecting Campbell datalogger to 12-volt battery
☐ (1)	4-Line phone junction box that is wired into the Campbell Scientific datalogger
☐ (as needed)	Gill Instruments Windsonic two-dimensional sonic anemometers and their vertical mounts
☐ (as needed)	Tripods
☐ (1)	Surveying equipment for mapping of instruments at time of setup
☐ (as needed)	Hoseclamps
☐ (1)	Mapping equipment
☐ (1)	Male-to-double female 9-pin serial cable
☐ (1)	Campbell Scientific's keypad interface
☐ (1)	Campbell Scientific's SM4M storage module
☐ (1)	Roll of electrical tape
☐ (1)	Plumber's putty
☐ (1)	Pencils or pens as needed
☐ (1)	Backpacks and/or "fanny" packs to hold equipment
☐ (2)	Pair of work gloves
☐ (2)	Helmets with lights
☐ (2)	Handheld flashlights for backup
☐ (~10)	Extra AA batteries for lights and GPS unit
☐ (1)	Hard copy of map with cave locations (on write-in-the-rain paper)
☐ (1)	GPS unit with all cave entrance waypoints pre-programmed
☐ (1)	Two-way radio (operational and fully charged)
☐ (1)	First Aid kit

Crew Leader's Signature: _____ Date: _____

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 3: Establishment and Location of Sampling Sites

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP explains the procedures used for establishing (i.e., selecting) and locating permanent sampling spaces (i.e., cave rooms and cross-sections) that should be followed by management and the project leader (establishing the sample space) as well as a project crew (locating the sample space).

Establishment of Sampling Sites

The protocol for monitoring cave meteorology throughout the Cumberland Piedmont Network was not written with the intent of establishing the particular locations where air temperature/relative humidity and air velocity should be measured. The intent of this protocol is only to provide the sampling approach for measurement of these air quality parameters. Particular cave rooms and cave cross-sections should be chosen to address management concerns for the cave section of interest. Essentially, this protocol provides for “carte blanche” selection of the cave space.

However, there are some basic criteria that a cave space must satisfy to be suitable as a sampling location. Mostly, these criteria provide limitations due to the sampling equipment that is used. For example, air temperature/relative humidity sampling can not be conducted along a cave ceiling that is more than about four meters high. This is because the air temperature/relative humidity probe is attached to the end of a section of PVC pipe and lifted (by hand) into place. A pole that is too long will be difficult to control. More sampling space criteria follow.

Sampling Space Criteria for Air Temperature/Relative Humidity:

1. Ceiling height should be roughly between one and four meters. Ceilings that are at less than one meter may force the probe assembly technician to be close to the air temperature probe, and the warmth of the technician’s body is likely to slightly elevate the air temperature/relative humidity measured. For ceilings that are more than about four meters

high, the probe assembly technician may have difficulty in safely lifting the air temperature probe to the ceiling.

2. The sample space must lie within reach of the reference point. The air temperature/relative humidity probe is tethered to the reference point via a signal cable that runs between the probe and the Campbell datalogger. The probe purchased at MACA was purchased with an eighteen meter cable, so the sample space with which MACA has experimented has a radius less than eighteen meters. Campbell Scientific, Inc. sells the probe used for this protocol with buyer-specified cable length up to ~300 meters. It is likely that a 30 meter cable will be sufficient for this protocol.

Sampling Space Criteria for Air Velocity Sampling:

1. Preferred cross-sections (when monitoring in conjunction with air temperature/relative humidity) are in the passage adjacent to the cave entrance.
2. Do not choose cross-sections that are within the intersection of two or more passages.
3. If an index for air exchange through a cave passage is desired, choose the cross-section with the most “regular” shape possible. In geometry, polygons can be classified as either regular or irregular. Regular polygons have the property that, when a line segment is drawn between any two vertices of the polygon, the line segment lies within the polygon and does not intersect any of the polygon’s lines. In terms of cave cross-sections, this means that there should be no pits, domes, high piles of rubble, steep depressions, or large stalactites/stalagmites.
4. If an index for air exchange through a cave passage is desired, choose the cross-section of the passage with the least area. Using the cross-section with the least area will maximize the air speed and minimize the potential for spatial heterogeneity in airflow.
5. If the cave cross-section has an area less than (about) three square meters, hunting for spatial heterogeneity in the air velocity field should be unnecessary. Velocities in cross-sections smaller than three square meters are likely homogeneous. Placing an anemometer at the cross-section’s centroid should be sufficient.

Location of Sampling Sites during a Sampling Session

1. Prior to sampling, obtain the current/revised sampling locations map and cave locations field list (with written driving and walking directions) on write-in-the-rain paper described in Section IV, procedure #1 in “Accessibility Check of Sampling Caves” (SOP#2 “Pre-Sampling”). Review map and field list, and become familiar with route and directions to each cave prior to departing for the field. *Note:* Caves on the cave locations field list should be arranged according to the anticipated order they will be encountered following the most time-efficient predetermined route.
2. Following the written driving directions in the appropriate cave locations field list (and GPS unit, if necessary), the crew leader and crew member(s) should drive the field vehicle to the designated parking spot (point on a road that is closest to the first cave entrance). Safely park the vehicle and locate the cave entrance on foot using the “Navigate” or “Go To” feature on the GPS unit (see operations manual for unit) in conjunction with the written directions and the map. The temporary piece of colored survey ribbon placed in the vicinity (≥ 15 m) the previous day (or two) during the pre-sampling site-check (SOP #2 “Pre-Sampling”, Site-Check of Sampling Sites, procedure #6) should aid in locating the entrance.

3. Confirm the correct entrance has been found by locating the permanent numbered brass marker (“cap”) anchored to a rock in the entrance, and/or the cave entrance description information. *Note:* presently, not all of Mammoth Cave National Park’s cave entrances have been permanently marked and many parks may not use such a marking system. The current permanent mark status for each cave should be noted on the cave locations field list.
4. Visually inspect cave entrance for new hazards (e.g., recent entrance collapse, unstable rocks in entrance, tree blocking entrance, flooding, ice in entrance, access road blocked or impassible, etc.). Make written notes regarding any such hazards and initial recommendations for later discussion with the project leader.
5. Continue as above to the next cave on the route until all cave entrances have been located. *Note:* once sampling at a cave is complete, please remember to remove the temporary ribbon placed at selected hard-to-find cave entrances to avoid compromising the “sensitivity” of these locations.

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 4a: Seasonal Sampling and Monitoring of Air Temperature and Relative Humidity

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP explains the procedures used for locating permanent sampling sites (i.e., cave entrances) that should be followed by all project crews during sampling *trips*. It also details the procedures for data collection and maintenance of in-situ equipment.

Sampling of Cave Air Temperature and Relative Humidity along a Cave Surface

This SOP provides detailed information on a sampling design and methodologies capable of capturing information about spatial variation of air temperature and relative humidity in cave spaces. The investigators have manufactured a sampling design that should be used for air temperatures and relative humidity along cave surfaces (floor, walls, and/or ceiling). Data collected can be used to:

- Provide a modeled time series of mean air temperature and standard deviation along the surface of interest.
- Answer questions about spatial variability and potential drivers for this variability.
- Answer questions about biota response to spatial variability.
- Assess and/or project impacts of management actions upon spatial distribution of air temperature and relative humidity along cave surfaces.

Procedures follow for the collection of air temperature and relative humidity along a cave surface. Two sets of procedures are presented: one set for the collection of “seasonal” spatially distributed air temperature and relative humidity data using a handheld temperature/humidity probe and one set for the maintenance of long-term, automated temperature/humidity dataloggers. The long-term datalogger is used to generate the modeled time series mentioned in the bulleted list above.

Generally, the sequence of steps for data collection is the same for both “seasonal” data collection and long-term datalogger maintenance. The sequence is:

1. Complete the pre-sampling checklist.
2. Depart from office.
3. Arrive at the cave entrance.
4. Collect air temperature and relative humidity data near the entrance (for “seasonal” sampling).
5. Locate the appropriate cave room/landmark.
6. Setup, as necessary, equipment to complete “seasonal” sampling and/or service long-term datalogger.
7. Complete “seasonal” sampling and/or service long-term datalogger.
8. Disassemble and pack, as necessary, equipment used to complete “seasonal” sampling and/or service long-term datalogger.
9. Repeat steps (5) through (8) for subsequent locations in the current cave.
10. Return to surface.
11. Collect air temperature and relative humidity data near the entrance (for “seasonal” sampling).
12. Depart from current cave.
13. If more caves are to be sampled, return to (3). Otherwise, go to (14).
14. Return to office.
15. Offload data collected to a personal computer.
16. Complete the post-sampling checklist.

More detailed procedures are presented in the following sections of this SOP.

Overview of “Seasonal” Spatial Sampling

The general outline for seasonal spatial sampling is:

- I.1. Collect data on pre-sample surface air conditions.
- I.2. Move to the desired in-cave data collection location.
- I.3. Set up siting equipment and datalogger.
- I.4. Collect plot data.
- I.5. Offload datalogger data and disassemble/stow equipment.
- I.6. Repeat steps (I.1) through (I.5) for subsequent sampling locations within the cave of interest.
- I.7. Collect data on post-sample surface air conditions.
- I.8. If another cave is to be sampled, move to that cave’s entrance and restart at step I.1.

Details for each of the above steps follow.

Detailed description of “Seasonal” Spatial Sampling

The set of steps that follow assume that the pre-sampling checklist has been completed and that the sampling crew has arrived at the cave of interest.

- I.1. Air temperature and relative humidity data should first be collected outside the cave entrance in an area that is free from the effects of air flowing out of the cave system. Since the

location at which data are collected should remain the same throughout the year, assure that the site is free of the cave's influence during *all* seasons.

- a) *Power the datalogger.* There is no mechanical power switch on the CR10X, and the battery should not be plugged into the datalogger. Place the battery into the circuit by first locating the power supply line that is plugged into the wiring panel's "Power In" port, and then connecting the loose ends to the battery's terminals. The red connector from the power supply line should be connected to the red (or positive) battery terminal, and the black connector from the power supply line should be connected to the black (or negative) battery terminal. Terminals should also be connected in that order; that is, red-to-red first, and black-to-black second.
- b) *Connect the keypad to the datalogger.* Campbell Scientific's CR10KD is a keypad display that allows the user to interact with the CR10X datalogger. The user can view data stored and being collected by the datalogger. The keypad can also be used to program the datalogger in the field. Connection of the keypad to the datalogger is accomplished through the use of a 9-pin serial cable. For this application, either the male-to-double female 9-pin serial cable (the cable that Campbell Scientific supplies with the keypad) or the ~2m male-to-female 9-pin serial cable may be used to connect the keypad to the datalogger. Simply connect the female end of the cable to the male port on the keypad, and then connect the male end of the cable to the female port on the wiring panel.
- c) *Key in *63A on the keypad.* Having just plugged the keypad into the datalogger, the keypad display will frequently be scrambled. To remedy this problem, the user may key in *0. This keystroke sequence will take the user to the "Log" screen. *63A may now be keyed to allow the user to view the instantaneous air temperature measurement. The *6 portion of the keystroke sequence takes the user into a mode where intermediate data may be viewed (intermediate data are data that are being temporarily stored to be used for generation of data that will be permanently stored). The 3 portion of the keystroke sequence tells the datalogger which intermediate memory location the user wants to view. In this case, memory location 3 houses the air temperature measurement. The A portion of the keystroke sequence acts like an "Enter" key on a computer's keyboard: by pressing A, the user is shown location 3 as requested. The value that is shown should be a reasonable measurement for the current air temperature. The datalogger program used in this protocol is written so that new air temperature measurements are collected to intermediate storage each second, so the display will update each second. The values shown will likely fluctuate considerably (especially in the tenths and hundredths places).
- d) *Remove protective cap from the Vaisala at/rh probe.* There should be a protective yellow cap seated over the end of the Vaisala probe. This cap is intended to protect the sensor in the end of the housing but will also buffer the sensor against heat transfer. To eliminate this buffering effect, the protective cap must be removed and stowed for later usage.

- e) *Fill in the upper portion of the event form.* Several fields on the event data form should be completed at this point. These fields are: cave, date, Julian day, crew leader, and crew member.
- f) *Allow the at/rh probe to stabilize.* When the datalogger is initially powered on, the circuitry of the datalogger and at/rh probe is such that readings will not accurately reflect ambient conditions. The system must go through an acclimation or warm-up period during which the measurements will gradually begin stabilize. The crew should allow about 5 to 10 minutes for the system to acclimate.
- g) *Write down pre-sample air temperature.* Having allowed sufficient time for the system to acclimate, the user may view and log onto the sampling event field form the current air temperature. This datum should be listed on the pre-sample air temperature line. It is likely that the temperature on the display will show considerable variability (particularly beyond the tenths place). The user may ignore this variability and write the air temperature to the nearest tenths place.
- h) *Key in A on the keypad.* This will advance the user to intermediate storage location 4, where relative humidity values are stored.
- i) *Write down pre-sample relative humidity.* It is assumed at this step that the datalogger/probe system has stabilized. Therefore, the user may immediately accept the measurement shown as accurate. This datum should be listed on the post-sample relative humidity line. It is likely that the relative humidity measurement shown on the display will show considerable variability (particularly beyond the tenths place). The user may ignore this variability and write the relative humidity to the nearest tenths place.
- j) *Write down pre-sample time.* This is the time, local standard time (LST), at which the pre-sample measurements were collected.
- k) *Disconnect keypad / serial cable and replace Vaisala probe's protective cap.* Pre-sample data collection has, at this step, been completed. The user should disconnect the keypad and serial cable from one another and the datalogger. The keypad and serial cable should then be stowed.
- l) *Power down datalogger.* If the datalogger backpack or Pelican case is to be carried a long distance to the cave space to be sampled, the datalogger should be powered down. This eliminates the possibility of electrical shorts caused by jostling during transport (the jostling can result in live wires working loose which could result in damage-inducing electrical shorts and/or surges). Power down the datalogger by first disconnecting the positive lead from the red battery terminal and then disconnecting the negative lead from the black battery terminal. However, should the distance between surface collection point and cave space be short (less than about 700 feet) and the access easy, the user may leave the datalogger powered up during transport. This will eliminate the warm-up period once the crew has arrived at the cave space of interest.

- I.2. *Move to desired data collection location.* Walk to the cave room or passage to be sampled. Within the room or passage should be a defined point from which location data are collected for all sampling plots. This defined point within the space is called the *landmark*. Locate the landmark for the current cave space. The landmark is a known and mapped location in the cave system. Air temperature and relative humidity “plot” data will be paired with “plot” location data. These location data will give the coordinates of each at/rh plot relative to the landmark.
- I.3. *Set up siting equipment and datalogger.* Having arrived at the landmark of interest, the crew may begin to set up the hardware to be used for data collection.
- a. *Power up the datalogger.* If the datalogger was not powered down from previous usage, this step may be skipped. Otherwise, power the datalogger up by connecting the negative (black) lead to the black battery terminal and then connecting the positive (red) lead to the red battery terminal.
 - b. *Set and level the tripod.* Place the tripod at the landmark. Extend the legs of the tripod until the tripod is level. The tripod has a bubble level at its top; this level should be used to assure that the tripod has been properly leveled. Tighten leg set screws as necessary.
 - c. *Raise the tripod to the desired height.* Each landmark has a unique height to which the tripod should be extended. Look up the appropriate height for the landmark of interest and raise the tripod to that height. Secure all legs and cranks with set screws.
 - d. *Attach the surveying assembly to the tripod.* This instruction will be completed at a later date.
 - e. *Remove the protective cap from the Vaisala at/rh probe.* There should be a protective yellow cap seated over the end of the Vaisala probe. This cap is intended to protect the sensor in the end of the housing but will also buffer the sensor against heat transfer. To eliminate this buffering effect, the protective cap must be removed and stowed for later usage.
 - f. *Attach the Vaisala assembly to the ~2m PVC pipe.* Should the crew choose not to leave the Vaisala probe attached to the ~2m length piece of PVC pipe, attach the probe to the pole using a short length of electrical tape. Be certain to tape the probe about $\frac{1}{4}$ of the way up from its lower end.
 - g. *Attach the rangefinder target.* This instruction will be completed at a later date.
 - h. *Attach the keypad to the datalogger.* Connection of the keypad to the datalogger is accomplished through the use of a 9-pin serial cable. For this application, the authors strongly suggest using the ~2m male-to-female 9-pin serial cable. The cable’s long length allows the probe assembly technician more flexibility in positioning the keypad. Simply connect the female end of the cable to the male port on the keypad, and then connect the male end of the cable to the female port on the wiring panel.

- i. *Key in *66A to verify that the current plot ID is zero.* If the datalogger has just been powered up, then the plot ID shown by keying *66A should be zero. Otherwise, if the datalogger was last used to complete an air sampling run along some other cave surface, the plot ID will be that of the last plot sampled. To reset the plot ID to zero, the datalogger must be powered down. Disconnect the positive lead from its terminal, wait about 10 seconds, and reconnect that lead back onto its terminal. The datalogger will use about 10 seconds to return to the “Log” screen. Key *66A to verify that the plot ID was reset to zero.
- j. *Key in D to view the datalogger’s eight flags.* The CR10X has eight flags, labeled Flag 1, Flag 2, ... , Flag 8. Each flag can have a value of either zero or one. Flags are Boolean variables often used by programmers to trigger events. The programmer could dictate that if Flag 8 has a value of one, then power up some device (such as a light) external to the datalogger. The default value for flags is zero. The user can change the value of any flag through the flag screen. In order to view the flag screen, the user must be in *6 mode (e.g. viewing intermediate memory locations). Once in *6 mode, keying D will take the user to the flag screen. The display will consist of a sequence of eight digits. Each of these digits is the current value of a flag. The first digit corresponds to Flag 1, the second digit corresponds to Flag 2, and so on. The user may toggle between flag values by keying the numeric key that corresponds to the flag number. That is, key 1 to toggle Flag 1, key 2 to toggle Flag 2, and so forth. For seasonal air temperature and relative humidity collection, only Flag 1 is used. The value of Flag 1 is used to indicate whether the at/rh probe is in position at a plot and supplying valid data for that plot. A value of one means that the data are valid while a value of zero is assumed to mean that the data are not valid. Each time that the user sets Flag 1 to one, the plot number is increased by one. The program also contains a timer that is initiated when Flag 1 is set to one. Once the timer has counted thirty-six seconds, the value of Flag 1 is automatically reset to zero.
- k. *Allow at/rh measurements to stabilize.* When the datalogger is initially powered on, the circuitry of the datalogger and at/rh probe is such that readings will not accurately reflect ambient conditions. The system must go through an acclimation or warm-up period during which the measurements will gradually begin stabilize. Once the unit has been powered up, the crew should allow about 5 to 10 minutes for the system to acclimate. If the datalogger was not powered down before moving to the current landmark, this step may be skipped.
- l. *Set one (axial) laser on the floor to project an axial reference line.* This reference line is set up to help the crew collect data in an approximate grid. The laser line should remain in approximately the same location from one sampling event to the next, so it is important that the laser be aligned with recognizable features within the cave space. For example, in the authors’ sampled section of Mammoth Cave, the edge of a concrete pathway was used.

- m. *Set a second (transect) laser on the floor orthogonal to the axial laser and at the first transect.* This laser is used to guide the probe assembly technician along a relatively straight line as they collect plot data. The transect laser defines the transect.
- n. *Send the probe assembly technician to the first sampling plot.* At this point, all necessary preparations should have been completed. Data collection at sampling plots can now begin. The probe assembly technician should move to the rightmost or leftmost end of the transect laser line and prepare for data collection.

I.4. *Collect plot data.* Spatial data collection may now commence. Collection of these data uses the following steps:

- a. *Verify that the probe assembly technician is in position.* Assure that the probe assembly technician is in the proper position with the at/rh probe near the cave surface of interest.
- b. *Activate the datalogger's first flag.* Activate the first flag by keying 1 on the keypad. Activating Flag 1 changes a stored variable value to 1, thereby alerting the data analyst that data collected are valid. The probe assembly technician must remain in place with the probe near the surface of interest for the entire sampling interval (until the value of Flag 1 has returned to 0). Activating Flag 1 also advances the current plot number by one. The plot number displayed should therefore be either the number of the plot at which data are currently being collected or the plot number of the most recent plot completed.
- c. *Observe the existence/absence of biota at the plot.* This step may or may not be necessary. Some cave spaces may be known to harbor no organisms, so there is no reason to collect these data. In other spaces, organisms may be present and their status of concern to management. Collection of data in this instance is recommended since plot-level correlation between at/rh values and biota existence may suggest a cause-effect relationship between these two variables. Knowledge of this relationship may indicate management actions that could result in some desired effect on the organism of interest. In the case where organisms are present but there are no management concerns surrounding the organisms, the investigators nevertheless suggest collection of existence/absence data at the plot level. The organisms may later become of interest to management and possessing the data may then be useful.
- d. *Make any relevant plot notes.* These could include any phenomena that could impact at/rh measurements or existence of things that could be impacted by at/rh values. The crew may wish, for example, to include information on any lights, unusual airflow patterns, or tour groups passing through at the time of data collection.
- e. *Once Flag 1 has returned to zero, alert the probe assembly technician to move to the next plot.* For this at/rh SOP, the datalogger program was written so that the value of Flag 1 would remain one for thirty-six seconds after the flag is user-set to a value of one. The program then automatically resets the flag to its default value of zero. When the value of Flag 1 has automatically returned to a value of zero, the probe assembly technician

should move to the next sampling plot. The distance between plots should be ~2m. In order to gauge the distance between plots, the probe assembly technician may use the ~2m PVC pipe to which the at/rh probe is attached. The automated thirty-six second interval was chosen to insure that at least six five-second intervals would be sampled at each plot. For each of these five-second intervals, the program stores the mean air temperature and the mean relative humidity of five one-second measurements collected over the interval.

- f. *After a transect has been completed, move the transect laser to the next transect.* The probe assembly technician has, up to this point, been collecting data at plots that all lie along the same transect line. Once the current transect line has been sampled together with any non-transect, biota-loaded plots, the transect laser should be moved ~2m along the axial laser line to the next transect line. In order to gauge the distance between transects, the probe assembly technician may use the ~2m PVC pipe to which the at/rh probe is attached.
 - g. *Verify that the plot number in the datalogger and the most plot number used on the event data form coincide.* Plot-level at/rh data from the datalogger and plot-level data from the event data form must be properly paired for later data analysis. That is, at any given plot, the plot number shown in the datalogger file must be the same plot number for which data are written on the event data form. To assure this is case, the crew should periodically (at least at the end of each transect) verify that the datalogger plot number is equal to the most recent event data form plot number. To view the datalogger plot number, key *66A. To return to the flag screen, key D.
 - h. *Repeat steps (I.4.a) through (I.4.g) until all transect plots are completed.* Sampling of plots is completed one transect at a time (allowing the probe assembly technician to sample, where appropriate, biota-loaded sites along the way) until all transects have been completed. After all transect plots and biota-loaded plots have been sampled, sampling of the cave space is complete and the users may move to the next step.
 - i. *Replace the protective cap onto the Vaisala at/rh probe.* There should be a protective cap that was seated over the end of the Vaisala probe. This cap is intended to protect the sensor in the end of the housing from debris and gouging during movement. Please place that cap over the end of the probe before moving to the next cave space or returning to the cave entrance.
- I.5. *Offload datalogger data and disassemble/stow equipment.* To this point, the Campbell Scientific datalogger has been storing air temperature and relative humidity in “final” storage. Final storage is memory that is used for long-term storage of data. For this protocol, the investigators have prescribed that the data should be field-uploaded to a storage module for transport to the office. The storage module is a small, robust device used to house datalogger data. In order to move data from the datalogger to the storage module, the following sequence of steps must be followed.

- a. *Connect the keypad and storage module to the datalogger.* For collecting at/rh data at plots, it is likely that the ~2m male-to-female 9-pin serial cable was used. This cable has only one female connector, however, and will not allow both the keypad interface and the storage module to be connected simultaneously to the datalogger. So, this male-to-female serial cable must be disconnected and the shorter, double male-to-female 9-pin serial cable must be used. First, connect the storage module to either female connector. Then, connect the keypad to the remaining female connector. The loose male connector may then be connected to the datalogger's 9-pin serial port.
 - b. *Key in *871AAA3A to offload the data.* When the storage module/keypad assembly is first attached to the datalogger, it is possible that the keypad display may be scrambled. To remedy this problem, key *0 to return to the "Log" screen. It is now possible to command the datalogger to send its final storage data to the storage module. Key the sequence *871AAA3A to initiate the upload sequence.
 - c. *Allow ample time for the offload to be completed.* As data are moved from the datalogger to the storage module, the memory location of the current data is shown on the keypad display. These location number should be incrementing as the datalogger transfers one datum and then the next. Once the transfer is complete, the location numbers will no longer change and the user may move to the next step. Moving to the next step without allowing the transfer to complete will interrupt the offload and the complete dataset will not be stored in the storage module.
 - d. *Key in *0 on the keypad.* This returns the keypad display to the "Log" screen.
 - e. *Disconnect and stow the serial cable, keypad, and storage module.*
 - f. *Power down the datalogger.* If the datalogger backpack or Pelican case is to be carried a long distance to the cave entrance or the next cave space to be sampled, the datalogger should be powered down. This eliminates the possibility of electrical shorts caused by jostling during transport (the jostling can result in live wires working loose which could result in damage-inducing electrical shorts and/or surges). Power down the datalogger by first disconnecting the positive lead from the red battery terminal and then disconnecting the negative lead from the black battery terminal. However, should the distance between surface collection destinations be short (less than about 700 feet) and the access easy, the user may leave the datalogger powered up during transport. This will eliminate the warm-up period once the crew has arrived at the cave entrance or cave space of interest.
 - g. *Disassemble and stow all hardware for transport to the cave entrance or the next cave space to be sampled.*
- I.6. *Repeat steps (I.1) through (I.5) for subsequent sampling locations within the cave of interest.*
- I.7. *Collect post-sample air temperature and relative humidity at the cave entrance.* Air temperature and relative humidity data should once again be collected outside the cave

entrance in the same area where pre-sample data were collected. These pre-sample and post-sample data will be used to adjust cave meteorology data for variant surface conditions. The post-sample sequence that follows is the same as the pre-sample sequence.

- a. *Power the datalogger.* If the datalogger was not powered down from previous usage, this step may be skipped. Otherwise, power the datalogger up by connecting the negative (black) lead to the black battery terminal and then connecting the positive (red) lead to the red battery terminal.
- b. *Connect the keypad to the datalogger.* For this application, either the male-to-double female 9-pin serial cable (the cable that Campbell Scientific supplies with the keypad) or the ~2m male-to-female 9-pin serial cable may be used to connect the keypad to the datalogger. Simply connect the female end of the cable to the male port on the keypad, and then connect the male end of the cable to the female port on the wiring panel.
- c. *Key in *63A on the keypad.* Having just plugged the keypad into the datalogger, the keypad display will frequently be scrambled. To remedy this problem, the user may key in *0. This keystroke sequence will take the user to the “Log” screen. *63A may now be keyed to allow the user to view the instantaneous air temperature measurement. The value that is shown should be a reasonable measurement for the current air temperature. The datalogger program used in this protocol is written so that new air temperature measurements are collected to intermediate storage each second, so the display will update each second. The values shown will likely fluctuate considerably (especially beyond the tenths place).
- d. *Remove protective cap from the Vaisala at/rh probe.* The protective yellow cap should be seated over the end of the Vaisala probe. This cap is intended to protect the sensor in the end of the housing but will also buffer the sensor against heat transfer. To eliminate this buffering effect, the protective cap must be removed and stowed for later usage.
- e. *Allow the at/rh probe to stabilize.* When the datalogger is initially powered on, the circuitry of the datalogger and at/rh probe is such that readings will not accurately reflect ambient conditions. The system must go through an acclimation or warm-up period during which the measurements will gradually begin stabilize. Once the unit has been powered up, the crew should allow about 5 to 10 minutes for the system to acclimate. If the datalogger was not powered down before moving to the cave entrance, the full 5 to 10 minutes may not be necessary. Depending upon the differential between cave air temperature and surface air temperature, it may be necessary to wait only a minute or two.
- f. *Write down post-sample air temperature.* Having allowed sufficient time for the system to acclimate, the user may view and log onto the sampling event field form the current air temperature. This datum should be listed on the post-sample air temperature line. It is likely that the temperature on the display will show considerable variability (particularly beyond the tenths place). The user may ignore this variability and write the air temperature to the nearest tenths place.

- g. *Key in A on the keypad.* This will advance the user to intermediate storage location 4, where relative humidity values are stored.
- h. *Write down post-sample relative humidity.* It is assumed at this step that the datalogger/probe system has stabilized. Therefore, the user may immediately accept the measurement shown as accurate. This datum should be listed on the post-sample relative humidity line. It is likely that the relative humidity measurement shown on the display will show considerable variability (particularly beyond the tenths place). The user may ignore this variability and write the relative humidity to the nearest tenths place.
- i. *Write down post-sample time.* This is the time, local standard time (LST), at which the post-sample measurements were collected.
- j. *Disconnect keypad / serial cable and replace Vaisala probe's protective cap.* Post-sample data collection has, at this step, been completed. The user should disconnect the keypad and serial cable from one another and the datalogger. The keypad and serial cable should then be stowed.
- k. *Power down datalogger.* The datalogger should be powered down before moving to the next cave to be sampled or the office. Power down the datalogger by first disconnecting the positive lead from the red battery terminal and then disconnecting the negative lead from the black battery terminal.

I.8. If another cave is to be sampled, move to that cave's entrance and restart at step I.1.

Campbell Scientific Datalogger Modes and Commands

Two types of dataloggers are used for cave meteorology monitoring: HOBO dataloggers and Campbell Scientific's CR10X. The CR10X and its operation is the subject of this section. The CR10X has surrounding it a wiring panel to which sensors are attached. The wiring panel attaches to the CR10X via a 37-pin port and a 9-pin port (each is a D-type connector) at its side. The user interfaces with the datalogger via an RS-232 port on the wiring panel. This interaction is accomplished by plugging the CR10KD (a keypad with display) into the RS-232 port using a 9-pin serial connector. For this protocol, the primary interactions with the datalogger will be to:

- View and change, as necessary, date/time information.
- View air temperature and relative humidity data as they are being collected.
- Activate data collection events.
- Transfer data from the datalogger to the storage module.
- Return the datalogger to its normal state.

Each of these tasks is accomplished within a particular "mode." Modes are referred to as "modes" since, in order to enter the modes, the *-key must be depressed prior to the mode number. Modes used in this protocol are:

- *5 Mode – Display date/time information.
- *6 Mode – Display data in intermediate storage. Toggle flags within this mode.
- *8 Mode – Transfer data to the storage module.
- *0 Mode – Log data and display active program tables.

To enter each mode, key in * followed by the mode number. For most modes, this sequence will take the user directly into the requested mode. *6 mode, however, functions slightly differently. This mode is used to view intermediate storage, in which data are temporarily stored as they are collected from data sources (sources such as sensors or user-defined variables). Each measurement is stored in a “memory location” and memory locations use numeric labels. That is, there are memory locations 1, 2, 3, and so forth. Keying *6 does not take the user directly into *6 mode. The datalogger will wait to let the user key in the memory location to be viewed. For example, keying *612A places the user in *6 mode (from the *6 portion of the sequence) and allows the user to view the datum in memory location 12 (the 12 part of the sequence). The A portion of the sequence functions like an “enter” keystroke on a PC keyboard, communicating to the datalogger that the user has completed and accepted the keystroke sequence. Leaving a memory location out of the sequence (i.e. keying *6A) takes the user, by default, to memory location 1.

Side note: The CR10X has two types of data storage: intermediate storage and final storage. Intermediate storage contains raw data as collected directly from sensors or as defined by the user. Data in final storage are derivatives of the data in intermediate storage. For this air temperature and relative humidity SOP, as an example, the program executes once each second and stores these at/rh values into intermediate storage. At the end of a five second interval, these one-second values are averaged to generate the mean at/rh over that five second interval. These five-second averages are then placed in final storage and the one-second values are discarded. *6 mode displays *intermediate* data.

Within each mode, it may be possible to execute mode-specific commands. In *5 and *6 modes, for example, keying A advances the user through pieces of information. Keying B in these modes backs the user up through these same pieces of information. Descriptions of each mode and the functionalities of each follow.

- *0 Mode – Campbell Scientific refers to this mode as the “LOG data and indicate active Tables” mode. Keying *0 from any mode returns the user to a screen that may be called the home screen or log screen. In this mode, the user may see which program table(s) is (are) being executed. Program tables are distinct blocks of computer code that may be executed simultaneously and independently of one another. A CR10X program consists of two program tables (labeled tables 1 and 2). Entering *0 mode will display one of the following screens where each screen has the indicated meaning:
 - “LOG” – Indicates that no program table is being executed.
 - “LOG 1” – Indicates that program table 1 is being executed.
 - “LOG 2” – Indicates that program table 2 is being executed.
 - “LOG 12” – Indicates that program tables 1 and 2 are being executed.

For the cave meteorology protocol, only program table 1 is used.

- *5 Mode – Displays the current time and date information. Key A to advance (or ascend) through the list below and key B to back up through the list below.
 - Time
 - Year
 - Julian day
 - Time set screen
- *6 Mode – Displays intermediate memory used for temporary data storage. The display has the format LL : DDDDD, where LL is two digit memory location label and DDDDD is the most recent value stored to that location. The colon in the middle is used to indicate the program's execution; the colon flashes whenever the program is executed. Data shown are from the most recent program execution. A typical display may read "06 : 12.369" indicating that the most recent datum stored to memory location 6 is 12.369. For this SOP, the memory locations house the following information:
 - 01 – Cave identification code
 - 02 – Landmark identification code
 - 03 – Vaisala air temperature
 - 04 – Vaisala relative humidity
 - 05 – Event timer
 - 06 – Plot identification number
 - 07 – Current Flag 1 value

The user may view these data by either keying *6xxA (where xx is the desired memory location) or by keying *6A to enter *6 mode. Once in *6 mode, the user may press the A key to advance up through memory locations or press the B key to back up through memory locations.

- *8 Mode – This mode is used to transfer data from the datalogger to the storage module while in the field. Detailed information on this mode is unnecessary for this protocol. It is sufficient to know that keying *871AAA3A will transfer data from the datalogger's final storage to the storage module. The storage module tracks, for any given datalogger from which it offloads data, the starting point for uncollected data. The key sequence above takes advantage of this tracking capability to collect only the most recently collected data and not all of the data in final storage.

Flags

This SOP uses flags to mark data as valid or invalid. In this SOP, flags may be regarded as variables that the user may adjust. The CR10X supports eight such flags and each flag is referenced by a numeric identifier (i.e. Flag 1, Flag 2, ..., Flag 8). Each flag will have one of two possible values: either zero or one. To view (and alter) the value of these flags, the user should be in *6 mode (if the user is not in *6 mode, then *6A should be keyed). Once in *6 mode (while viewing any memory location), keying D will take the user to the flag screen where

each of the flags is shown. One possible display is “00100000”. The first digit is the value of Flag 1, the second digit is the value of Flag 2, and so on. In this example, all flags have values of zero, with the exception of Flag 3, which has a value of one.

The value of flags may be user-adjusted or program-adjusted. To user-adjust a flag value, press the numeric key that corresponds to the flag number. This will toggle that flag between the values zero and one. From the example, Flag 3 may be returned to a value of zero by keying 3 on the keypad (and back to one again by keying 3 a second time). For this SOP, flag 1 is used to indicate that at/rh data are being collected along a surface of interest. When this value is user-adjusted to a value of one, data are assumed valid and from a sampling plot. The program uses a timer to auto-reset the value of Flag 1 to zero. The user need only watch-and-wait for the value of Flag 1 to reset to zero and then move to the next sampling plot. The program allows thirty-six seconds to pass after Flag 1 has been user-adjusted to one. At the end of the thirty-six second interval, Flag 1 is program-adjusted back to zero.

Overview of “Continuous” Sampling

Continuous sampling of air temperature and relative humidity is accomplished at one point in a cave room or passage. Onset’s HOBO Pro RH/Temp dataloggers are used to collect these data on fifteen-minute intervals. These data are used to generate a modeled time series for the mean air temperature and relative humidity along surfaces of interest in the cave room or passage.

The procedure for launching a HOBO datalogger was outlined in SOP #2, and the procedure for location-selection was outlined in SOP #3a. The procedure for offloading data from a HOBO datalogger and changing batteries follow.

Offloading Data from a HOBO datalogger

1. Remove the cap from the top of the port access of the HOBO datalogger.
2. Using the HOBO shuttle’s stereo cable, connect the HOBO shuttle to the datalogger via the datalogger’s stereo port.
3. Initiate the data transfer process by depressing the small, black button at the top of the shuttle.
4. Wait for the offload process to complete. Watch the sequence of LED’s on the side of the shuttle. The Successful LED will flash once the offload is complete; move to Step 5. If the Comm failure LED flashes, it is possible that the stereo cable was not properly connected in Step 2. Depress the small black button on the top of the shuttle, disconnect and reconnect the shuttle to the datalogger, and press the black button again. If this is unsuccessful, disconnect the shuttle from the datalogger and troubleshoot the datalogger.
5. Depress the small, black button at the top of the shuttle.
6. Disconnect the datalogger from the shuttle, stowing the stereo cable with the shuttle.
7. Look down into the datalogger’s stereo port. A flashing red LED should be visible. If the LED is not flashing, go back to Step 1. If this has already been attempted, the datalogger may be malfunctioning and should be troubleshot.
8. Replace the cap at the top of the port access.
9. Place the datalogger at its sampling location.
10. Complete the field form.

Offloading Data from a HOB0 datalogger and replacing the datalogger's battery

1. Remove the back of the datalogger.
2. Remove the old battery and replace with a new battery.
3. Remove the cap from the top of the port access of the HOB0 datalogger.
4. Using the HOB0 shuttle's stereo cable, connect the HOB0 shuttle to the datalogger via the datalogger's stereo port.
5. Initiate the data transfer process by depressing the small, black button at the top of the shuttle.
6. Wait for the offload process to complete. Watch the sequence of LED's on the side of the shuttle. The Successful LED will flash once the offload is complete; move to Step 7. If the Comm failure LED flashes, it is possible that the stereo cable was not properly connected in Step 2. Depress the small black button on the top of the shuttle, disconnect and reconnect the shuttle to the datalogger, and press the black button again. If this is unsuccessful, disconnect the shuttle from the datalogger and troubleshoot the datalogger.
7. Depress the small, black button at the top of the shuttle.
8. Disconnect the datalogger from the shuttle, stowing the stereo cable with the shuttle.
9. Look down into the datalogger's stereo port. A flashing red LED should be visible. If the LED is not flashing, go back to Step 4. If this has already been attempted, the datalogger may be malfunctioning and should be troubleshoot.
10. Around the bottom of the datalogger is an o-ring. Clean and grease this o-ring. Clean the groove in which the o-ring is seated. Replace the cleaned and greased o-ring.
11. Clean the metal plate that serves as the back of the datalogger.
12. There is a small packet of dessicant in the datalogger. Making sure that this packet is still in the datalogger, replace the metal plate on the back of the datalogger.
13. Replace the cap at the top of the port access.
14. Place the datalogger at its sampling location.
15. Complete the field form.

The HOB0 Shuttle is capable of holding multiple files. So, several sampling locations may be serviced without transferring the data to a PC. When the sampling crew returns to the office, the data may be offloaded from the shuttle to a PC as outlined in SOP #5.

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 4b: Seasonal Sampling and Monitoring of Cross-Sectional Air Velocity

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP explains the procedures used for establishing (i.e., selecting) and locating permanent sampling sites (i.e., cave entrances) that should be followed by all project crews both: (1) prior to sampling (if an additional site is to be added) and (2) during sampling *trips*.

Seasonal Sampling of Cave Air Velocity

It is the intent of this SOP to provide detailed information on a sampling design and methodologies capable of capturing information about spatial homogeneity/non-homogeneity of airflow within a cave cross-section. The authors have manufactured a sampling design that should be used for air velocity monitoring within a cave cross-section. Data collected can be used to:

- Answer questions about spatial variability and potential drivers for this variability.
- Provide a representative time series for air velocity within a cave cross-section.
- Provide air velocity data that may be used to predict, through statistical models, air temperatures at plots within a cave space.
- Through use of the models above, project impacts of management actions upon air temperatures at said plots within a cave space.
- Assess and/or project impacts of management actions upon spatial distribution of air velocity within a cave cross-section.

Procedures follow for the collection of air velocity within a cave cross-section. Three sets of procedures are presented, one set for each of the following events:

- Equipment installation.
- Equipment removal.
- Interim equipment maintenance (when no instruments will be installed or removed).

Generally, the same sequence of steps is followed for equipment installation, equipment removal, and interim equipment maintenance. The sequence is:

1. Complete the pre-sampling checklist.
2. Depart from office.
3. Arrive at the cave entrance.
4. Locate the appropriate cave cross-section.
5. If installing instruments, set up anemometers and dataloggers as prescribed for the cross-section of interest. This setup includes the mapping of anemometer locations within the cross-section.
6. Service datalogger(s).
7. If removing instruments, prepare anemometers and dataloggers for removal as prescribed for the cross-section of interest.
8. Repeat steps (4) through (7) for subsequent locations in the current cave.
9. Return to surface.
10. Depart from current cave.
11. If more caves are to be sampled, return to (3). Otherwise, go to (12).
12. Return to office.
13. Offload data collected to a personal computer.
14. Complete the post-sampling checklist.

More detailed procedures are presented in subsequent sections of this SOP.

Equipment Installation

1. *Move to the desired cave cross-section and locate its landmark.* Walk to the cave cross-section to be sampled. Within or near the cross-section should be a defined point from which anemometer head locations are mapped. This defined point within the space is called the *landmark*. The landmark is a known and mapped location in the cave system. Locate the landmark for the current cave cross-section.
2. *Assemble and install tripods, as necessary.* If this is not a new cross-section, one or more tripods could be present. Additional tripods, however, may be needed. Install additional tripods as necessary.
3. *Attach anemometer heads to tripods, and run anemometer cables.* One cable attaches to each anemometer head via a quick-connect. To connect the cable to the anemometer, orient the connector so that the connector's wire ports align with the anemometer head's wire ports, gently insert the cable quick-connect around the anemometer head's quick connect, and then turn the nut around the cable's quick connect to secure the connection. Run the anemometer cable to the appropriate datalogger enclosure. Repeat for additional anemometers.
4. *If the cross-section of interest has not been mapped, map the cross-section's size and shape.* This section of instructions will be completed at a later time, when the hardware necessary for mapping a cross-section has been constructed.
5. *Map the locations of the anemometer heads.* This section of instructions will be completed at a later time, when the hardware necessary for mapping of anemometer head locations has been constructed.
6. *Connect anemometer cabling to the datalogger.* The loose ends of each anemometer's cabling should have attached an RJ11 adapter. Route this end of the cabling through the hole

in the side of the Pelican case. Plug the RJ11 adapter into any port on the 4-wire phone line distribution box. Repeat for additional anemometers. Once the final anemometer has been plugged in, seal the opening in the Pelican case with plumber's putty.

7. *Place fresh desiccant in the Pelican case.* Desiccant may be used in either of two forms: loose pebbles that are poured into a small cup housed within the pelican case or encased desiccant packs. Be certain that desiccant is not "spent" (meaning not saturated with water). Spent desiccant may be dried using an oven.
8. *Power up the datalogger.* There is no mechanical power switch on the CR10X, and the battery should not be plugged into the datalogger. Place the battery into the circuit by first locating the power supply line that is plugged into the wiring panel's "Power In" port, and then connecting the loose ends to the battery's terminals. The black connector from the power supply line should be connected to the black (or negative) battery terminal, and the red connector from the power supply line should be connected to the red (or positive) battery terminal. Terminals should also be connected in that order; that is, black-to-black first, and red-to-red second.
9. *Connect the keypad to the datalogger.* Campbell Scientific's CR10KD is a keypad display that allows the user to interact with the CR10X datalogger. The user can view data stored and being collected by the datalogger. The keypad can also be used to program the datalogger in the field. Connection of the keypad to the datalogger is accomplished through the use of a 9-pin serial cable. For this application, either the male-to-double female 9-pin serial cable (the cable that Campbell Scientific supplies with the keypad) or the ~2m male-to-female 9-pin serial cable (used in the air temperature and relative humidity SOP) may be used to connect the keypad to the datalogger. Simply connect the female end of the cable to the male port on the keypad, and then connect the male end of the cable to the female port on the wiring panel.
10. *Verify datalogger date and time is correct (*5 mode).* Keying in *5 on the keypad will show the user the datalogger's time. Verify that the time shown (which should be local standard time) is the correct time. If the time shown is incorrect, key AAA to view the time set screen. Enter the time for the next whole minute on your watch. When your watch reaches that next whole minute, key A on the keypad. The display should now show the corrected time. To verify that the date is correct, from the time screen, key in A to view the year and key A again to view the Julian day. If either of these is incorrect, key in the correct year or day within its screen and key A.
11. *Verify that anemometer data are reasonable (*6 mode).* Keying *6A takes the user to the datalogger's first intermediate storage location. Keying A advances the user through the memory locations, while keying B will back the user through those same locations. A field list follows; data viewed depends upon which datalogger is being serviced.

Datalogger 1

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 0 diagnostic
- 06 – Anemometer 0 wind speed
- 07 – Anemometer 0 wind direction
- 08 – Anemometer 0 sample count
- 09 – Anemometer 1 diagnostic
- 10 – Anemometer 1 wind speed
- 11 – Anemometer 1 wind direction
- 12 – Anemometer 1 sample count
- 13 – Anemometer 2 diagnostic
- 14 – Anemometer 2 wind speed
- 15 – Anemometer 2 wind direction
- 16 – Anemometer 2 sample count

Datalogger 2

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 3 diagnostic
- 06 – Anemometer 3 wind speed
- 07 – Anemometer 3 wind direction
- 08 – Anemometer 3 sample count
- 09 – Anemometer 4 diagnostic
- 10 – Anemometer 4 wind speed
- 11 – Anemometer 4 wind direction
- 12 – Anemometer 4 sample count
- 13 – Anemometer 5 diagnostic
- 14 – Anemometer 5 wind speed
- 15 – Anemometer 5 wind direction
- 16 – Anemometer 5 sample count

Write the observed values onto the field form. If data are unreasonable, check that all equipment is properly connected to the datalogger and allow time for the datalogger to update the data.

12. *Key *0 to return the datalogger to the “Log” screen.*
13. *Disconnect the keypad.*
14. *Stow the keypad and its 9-pin serial connector-cable.*
15. *Close the Pelican case to weatherproof the datalogger.* Be certain that cabling residing within the Pelican case will not be pinched between the top and bottom lips of the case as it is closed.
16. *Take site photographs.* Two photographs should be taken: a photograph facing outcave and a photograph facing incave. Photographs should also be taken in that order: facing outcave followed by facing incave.
17. *Complete the Site Setup Form.*
18. *Stow remaining equipment and move to next site or the cave surface.*

Equipment Removal

1. *Verify that anemometers are unobstructed and tripods/cabling are secure.* Equipment should be undisturbed since previous visit. Be certain that no foreign material is lying on or near the anemometer heads. Also be certain that anemometer heads have not fallen or otherwise moved from their intended positions.
2. *Open Pelican case.*
3. *Connect keypad and storage module to datalogger using male-to-double female 9-pin serial cable.*
4. *Verify that datalogger date and time is correct (*5 mode).* Keying in *5 on the keypad will show the user the datalogger’s time. Verify that the time shown (which should be local standard time) is the correct time. If the time shown is incorrect, key AAA to view the time set screen. Enter the time for the next whole minute on your watch. When your watch

reaches that next whole minute, key A on the keypad. The display should now show the corrected time. To verify that the date is correct, from the time screen, key in A to view the year and key A again to view the Julian day. If either of these is incorrect, key in the correct year or day within its screen and key A. Note any corrections on the field form.

5. *Verify that anemometer data are reasonable (*6 mode).* Keying *6A takes the user to the datalogger's first intermediate storage location. Keying A advances the user through the memory locations, while keying B will back the user through those same locations. A field list follows; data viewed depends upon which datalogger is being serviced.

Datalogger 1

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 0 diagnostic
- 06 – Anemometer 0 wind speed
- 07 – Anemometer 0 wind direction
- 08 – Anemometer 0 sample count
- 09 – Anemometer 1 diagnostic
- 10 – Anemometer 1 wind speed
- 11 – Anemometer 1 wind direction
- 12 – Anemometer 1 sample count
- 13 – Anemometer 2 diagnostic
- 14 – Anemometer 2 wind speed
- 15 – Anemometer 2 wind direction
- 16 – Anemometer 2 sample count

Datalogger 2

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 3 diagnostic
- 06 – Anemometer 3 wind speed
- 07 – Anemometer 3 wind direction
- 08 – Anemometer 3 sample count
- 09 – Anemometer 4 diagnostic
- 10 – Anemometer 4 wind speed
- 11 – Anemometer 4 wind direction
- 12 – Anemometer 4 sample count
- 13 – Anemometer 5 diagnostic
- 14 – Anemometer 5 wind speed
- 15 – Anemometer 5 wind direction
- 16 – Anemometer 5 sample count

Write the observed values onto the field form. If data are unreasonable, check that all equipment is properly connected to the datalogger and allow time for the datalogger to update the data. Note any problems on the field form.

6. *Offload data by keying *871AAA3A.* This key sequence may be entered from any mode. Data transfer will begin immediately.
7. *Change desiccant while offload is completing.* Desiccant may be used in either of two forms: loose pebbles that are poured into a small cup housed within the pelican case or encased desiccant packs. Be certain that desiccant being placed into the Pelican case is not "spent" (meaning not saturated with water). Spent desiccant may be dried using an oven.
8. *Allow ample time for the offload to be completed.* Download time for a typical file is about one minute. During the download, the keypad will display the current memory location (identified by a location number, similar to identification system for intermediate storage) being transferred. As the download progresses, the memory location number will continue to increment until the download is complete. When the download is complete, the memory location number will be that of the most recent datum transferred.
9. *Key in *0 on the keypad.* This will return the datalogger to the "Log" screen.
10. *If the datalogger and all of its associated anemometers will be removed, the following set of steps should be followed.*

- 10a. *Power down the datalogger.* First, disconnect the positive (red) terminal connector from its battery terminal and then disconnect the negative (black) terminal connector from its battery terminal.
- 10b. *Disconnect each datalogger from the phone line junction box.* Simply unplug the RJ11 adapter at the end of the anemometer's cabling.
- 10c. *Remove anemometer heads from supporting tripods and disassemble tripods as necessary.*
- 10d. *Stow supplies for transport to the office.*
- 10e. *Proceed to Step (18).*
11. *If the datalogger will not be removed, but at least one of its connected anemometers is to be removed, the following set of steps should be followed.*
 - 11a. *Power down the datalogger.* First, disconnect the positive (red) terminal connector from its battery terminal and then disconnect the negative (black) terminal connector from its battery terminal.
 - 11b. *As appropriate, disconnect each datalogger from the phone line junction box.* Simply unplug the RJ11 adapter at the end of the anemometer's cabling.
 - 11c. *Power up the datalogger.* First, connect the negative (black) terminal connector from its battery terminal and then connect the positive (red) terminal connector from its battery terminal.
 - 11d. *Proceed to Step (12).*
12. *Change datalogger battery.* Note: battery exchange should be performed using a wiring pig (a wiring harness that allows simultaneous connection of two batteries so that the datalogger is never without power). Instructions for construction of this pig are included in this protocol. The wiring pig consists of a quick connect for attaching the wiring assembly into the datalogger and two pairs of battery terminal connectors. One pair of terminal connectors should not be attached to a battery. With the depleted battery in place, connect the charged battery to the unused pair of terminal connectors. The negative (black) battery terminal should be connected first and the positive (red) battery terminal second. Next, disconnect the depleted battery by detaching the positive (red) terminal first and the negative (black) terminal second.
13. *Key *64A to verify that the new battery voltage is approximately between 13.0 and 13.1 volts.* The maximum voltage will vary from one brand of battery to the next, and the batteries used during the testing of this protocol had as a maximum voltage 13.1 volts.
14. *Key in *0.* This returns the datalogger to the "Log" screen.
15. *Disconnect and stow the serial cable, keypad, and storage module.*
16. *Close the Pelican case.* Prior to closing the case, be certain that no cabling will be pinched between the case's edges.
17. *Verify that site is still secure (no cabling has been kicked out of place, etc).*
18. *Complete the field observer form.*
19. *Stow any remaining supplies and depart from the location.*
20. *Service additional locations, repeating steps (1) through (19) at each location.*
21. *Return to office.*
22. *Transfer data from the storage module to a PC.* The process for data transfer is outlined in the section: *Campbell Scientific's Storage Module Offload Procedure* of SOP #5 – Post Sampling.

Interim Equipment Maintenance

1. *Verify that anemometers are unobstructed and tripods/cabling are secure.* Equipment should be undisturbed since previous visit. Be certain that no foreign material is lying on or near the anemometer heads. Also be certain that anemometer heads have not fallen or otherwise moved from their intended positions.
2. *Open Pelican case.*
3. Connect keypad and storage module to datalogger using male-to-double female 9-pin serial cable.
4. *Verify that datalogger date and time is correct (*5 mode).* Keying in *5 on the keypad will show the user the datalogger's time. Verify that the time shown (which should be local standard time) is the correct time. If the time shown is incorrect, key AAA to view the time set screen. Enter the time for the next whole minute on your watch. When your watch reaches that next whole minute, key A on the keypad. The display should now show the corrected time. To verify that the date is correct, from the time screen, key in A to view the year and key A again to view the Julian day. If either of these is incorrect, key in the correct year or day within its screen and key A. Note any corrections on the field form.
5. *Verify that anemometer data are reasonable (*6 mode).* Keying *6A takes the user to the datalogger's first intermediate storage location. Keying A advances the user through the memory locations, while keying B will back the user through those same locations. A field list follows; data viewed depends upon which datalogger is being serviced.

Datalogger 1

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 0 diagnostic
- 06 – Anemometer 0 wind speed
- 07 – Anemometer 0 wind direction
- 08 – Anemometer 0 sample count
- 09 – Anemometer 1 diagnostic
- 10 – Anemometer 1 wind speed
- 11 – Anemometer 1 wind direction
- 12 – Anemometer 1 sample count
- 13 – Anemometer 2 diagnostic
- 14 – Anemometer 2 wind speed
- 15 – Anemometer 2 wind direction
- 16 – Anemometer 2 sample count

Datalogger 2

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 3 diagnostic
- 06 – Anemometer 3 wind speed
- 07 – Anemometer 3 wind direction
- 08 – Anemometer 3 sample count
- 09 – Anemometer 4 diagnostic
- 10 – Anemometer 4 wind speed
- 11 – Anemometer 4 wind direction
- 12 – Anemometer 4 sample count
- 13 – Anemometer 5 diagnostic
- 14 – Anemometer 5 wind speed
- 15 – Anemometer 5 wind direction
- 16 – Anemometer 5 sample count

Write the observed values onto the field form. If data are unreasonable, check that all equipment is properly connected to the datalogger and allow time for the datalogger to update the data. Note any problems on the field form.

6. *Offload data by keying *871AAA3A.* This key sequence may be entered from any mode. Data transfer will begin immediately.
7. *Change desiccant while offload is completing.* Desiccant may be used in either of two forms: loose pebbles that are poured into a small cup housed within the pelican case or encased

desiccant packs. Be certain that desiccant being placed into the Pelican case is not “spent” (meaning the dessicant should not be saturated with water). Spent desiccant may be dried using an oven.

8. *Allow ample time for the offload to be completed.* Download time for a typical file is about one minute. During the download, the keypad will display the current memory location (identified by a location number, similar to identification system for intermediate storage) being transferred. As the download progresses, the memory location number will continue to increment until the download is complete. When the download is complete, the memory location number will be that of the most recent datum transferred.
9. *Key in *0 on the keypad.* This will return the datalogger to the “Log” screen.
10. *Change datalogger battery.* Note: battery exchange should be performed using a wiring pig (a wiring harness that allows simultaneous connection of two batteries so that the datalogger is never without power). Instructions for construction of this pig are included in this protocol. The wiring pig consists of a quick connect for attaching the wiring assembly into the datalogger and two pairs of battery terminal connectors. One pair of terminal connectors should not be attached to a battery. With the depleted battery in place, connect the charged battery to the unused pair of terminal connectors. The negative (black) battery terminal should be connected first followed by the positive (red) battery terminal second. Next, disconnect the depleted battery by detaching the positive (red) terminal first followed by the negative (black) terminal second.
11. *Key *64A to verify that the new battery voltage is approximately between 13.0 and 13.1 volts.* The maximum voltage will vary from one brand of battery to the next, and the batteries used during the testing of this protocol had as a maximum voltage 13.1 volts.
12. *Key in *0.* This returns the datalogger to the “Log” screen.
13. *Disconnect and stow the serial cable, keypad, and storage module.*
14. *Close the Pelican case.* Prior to closing the case, be certain that no cabling will be pinched between the case’s edges.
15. *Verify that site is still secure (no cabling has been kicked out of place, etc).*
16. *Complete the field observer form.*
17. *Stow any remaining supplies and depart from the location.*
18. *Service additional locations, repeating steps (1) through (17) at each location.*
19. *Return to office.*
20. *Transfer data from the storage module to a PC.* The process for data transfer is outlined in the section: *Campbell Scientific’s Storage Module Offload Procedure* of SOP #5 – Post Sampling.

Campbell Scientific Datalogger Modes and Commands:

Two types of dataloggers are used for cave meteorology monitoring: HOBO dataloggers and Campbell Scientific’s CR10X. The CR10X and its operation is the subject of this section. The CR10X has surrounding it a wiring panel to which sensors are attached. The wiring panel attaches to the CR10X via a 37-pin port and a 9-pin port (each is a D-type connector) at its side. The user interfaces with the datalogger via an RS-232 port on the wiring panel. This interaction is accomplished by plugging the CR10KD (a keypad with display) into the RS-232 port using a 9-pin serial connector. For this protocol, the primary interactions with the datalogger will be to:

- View and change, as necessary, date/time information.
- View air temperature and relative humidity data as they are being collected.
- Activate data collection events.
- Transfer data from the datalogger to the storage module.
- Return the datalogger to its normal state.

Each of these tasks is accomplished within a particular “mode.” Modes are referred to as “* modes” since, in order to enter the modes, the *-key must be depressed prior to the mode number. Modes used in this protocol are:

- *5 Mode – Display date/time information.
- *6 Mode – Display data in intermediate storage. Toggle flags within this mode.
- *8 Mode – Transfer data to the storage module.
- *0 Mode – Log data and display active program tables.

To enter each mode, key in * followed by the mode number. For most modes, this sequence will take the user directly into the requested mode. *6 mode, however, functions slightly differently. This mode is used to view intermediate storage, in which data are temporarily stored as they are collected from data sources (sources such as sensors or user-defined variables). Each measurement is stored in a “memory location” and memory locations use numeric labels. That is, there are memory locations 1, 2, 3, and so forth. Keying *6 does not take the user directly into *6 mode. The datalogger will wait to let the user key in the memory location to be viewed. For example, keying *612A places the user in *6 mode (from the *6 portion of the sequence) and allows the user to view the datum in memory location 12 (the 12 part of the sequence). The A portion of the sequence functions like an “enter” keystroke on a PC keyboard, communicating to the datalogger that the user has completed and accepted the keystroke sequence. Leaving a memory location out of the sequence (i.e. keying *6A) takes the user, by default, to memory location 1.

Side note: The CR10X has two types of data storage: intermediate storage and final storage. Intermediate storage contains raw data as collected directly from sensors or as defined by the user. Data in final storage are derivatives of the data in intermediate storage. For this air temperature and relative humidity SOP, as an example, the program executes once each second and stores these at/rh values into intermediate storage. At the end of a five second interval, these one-second values are averaged to generate the mean at/rh over that five second interval. These five-second averages are then placed in final storage and the one-second values are discarded. *6 mode displays *intermediate* data.

Within each mode, it may be possible to execute mode-specific commands. In *5 and *6 modes, for example, keying A advances the user through pieces of information. Keying B in these modes backs the user up through these same pieces of information. Descriptions of each mode and the functionalities of each follow.

- *0 Mode – Campbell Scientific refers to this mode as the “LOG data and indicate active Tables” mode. Keying *0 from any mode returns the user to a screen that may be called the home screen or log screen. In this mode, the user may see which program table(s) is (are)

being executed. Program tables are distinct blocks of computer code that may be executed simultaneously and independently of one another. A CR10X program consists of two program tables (labeled tables 1 and 2). Entering *0 mode will display one of the following screens where each screen has the indicated meaning:

- “LOG” – Indicates that no program table is being executed.
- “LOG 1” – Indicates that program table 1 is being executed.
- “LOG 2” – Indicates that program table 2 is being executed.
- “LOG 12” – Indicates that program tables 1 and 2 are being executed.

For the cave meteorology protocol, only program table 1 is used.

- *5 Mode – Displays the current time and date information. Key A to advance (or ascend) through the list below and key B to back up through the list below.
 - Time
 - Year
 - Julian day
 - Time set screen
- *6 Mode – Displays intermediate memory used for temporary data storage. The display has the format LL : DDDDD, where LL is two digit memory location label and DDDDD is the most recent value stored to that location. The colon in the middle is used to indicate the program’s execution; the colon flashes whenever the program is executed. Data shown are from the most recent program execution. A typical display may read “07 : 12.369” indicating that the most recent datum stored to memory location 7 is 12.369. For this SOP, the memory locations house the following information:

Datalogger 1

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 0 diagnostic
- 06 – Anemometer 0 wind speed
- 07 – Anemometer 0 wind direction
- 08 – Anemometer 0 sample count
- 09 – Anemometer 1 diagnostic
- 10 – Anemometer 1 wind speed
- 11 – Anemometer 1 wind direction
- 12 – Anemometer 1 sample count
- 13 – Anemometer 2 diagnostic
- 14 – Anemometer 2 wind speed
- 15 – Anemometer 2 wind direction
- 16 – Anemometer 2 sample count

Datalogger 2

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 3 diagnostic
- 06 – Anemometer 3 wind speed
- 07 – Anemometer 3 wind direction
- 08 – Anemometer 3 sample count
- 09 – Anemometer 4 diagnostic
- 10 – Anemometer 4 wind speed
- 11 – Anemometer 4 wind direction
- 12 – Anemometer 4 sample count
- 13 – Anemometer 5 diagnostic
- 14 – Anemometer 5 wind speed
- 15 – Anemometer 5 wind direction
- 16 – Anemometer 5 sample count

The user may view these data by either keying *6xxA (where xx is the desired memory location) or by keying *6A to enter *6 mode. Once in *6 mode, the user may press the A key to advance up through memory locations or press the B key to back up through memory locations.

- *8 Mode – This mode is used to transfer data from the datalogger to the storage module while in the field. Detailed information on this mode is unnecessary for this protocol. It is sufficient to know that keying *871AAA3A will transfer data from the datalogger's final storage to the storage module. The storage module tracks, for any given datalogger from which it offloads data, the starting point for uncollected data. The key sequence above takes advantage of this tracking capability to collect only the most recently collected data and not all of the data in final storage.

Flags

This SOP uses flags to mark data as valid or invalid. In this SOP, flags may be regarded as variables that the user may adjust. The CR10X supports eight such flags and each flag is referenced by a numeric identifier (i.e. Flag 1, Flag 2, ..., Flag 8). Each flag will have one of two possible values: either zero or one. To view (and alter) the value of these flags, the user should be in *6 mode (if the user is not in *6 mode, then *6A should be keyed). Once in *6 mode (while viewing any memory location), keying D will take the user to the flag screen where each of the flags is shown. One possible display is "00100000". The first digit is the value of Flag 1, the second digit is the value of Flag 2, and so on. In this example, all flags have values of zero, with the exception of Flag 3, which has a value of one.

The value of flags may be user-adjusted or program-adjusted. To user-adjust a flag value, press the numeric key that corresponds to the flag number. This will toggle that flag between the values zero and one. From the example, Flag 3 may be returned to a value of zero by keying 3 on the keypad (and back to one again by keying 3 a second time). For this SOP, flag 1 is used to indicate that at/rh data are being collected along a surface of interest. When this value is user-adjusted to a value of one, data are assumed valid and from a sampling plot. The program uses a timer to auto-reset the value of Flag 1 to zero. The user need only watch-and-wait for the value of Flag 1 to reset to zero and then move to the next sampling plot. The program allows thirty-six seconds to pass after Flag 1 has been user-adjusted to one. At the end of the thirty-six second interval, Flag 1 is program-adjusted back to zero.

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 5: Post-Sampling

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This Standard Operating Procedure explains procedures that all field observers using the Cave Meteorology Monitoring Protocol for the Cumberland Piedmont Network (CPN) should be familiar with and follow after the field sampling is completed.

Procedures

1. Organize field data forms and check that they have been filled out completely. As a rule, all data forms need to be reviewed for completeness and accuracy by the crew leader immediately upon returning from the field (SOP #6 “Data Management”, Data Flow). However, because of the number of caves involved and crew members, some deficiencies in data recording may not be identified until all data forms have been organized and reviewed as a group (e.g., when pre-sample time for a particular cave has inadvertently been missed by a sampling crew). Once the data forms have been reviewed, and the data entered into the database, verified and validated, the project leader will make photocopies to serve as backups, and have originals submitted to the appropriate archive (SOP #6 “Data Management”; Data Entry, Data Verification, and Data Validation).
2. Check and repair/replace all supplies and equipment prior to returning them to their proper storage areas, and each NPS staff member’s office (helmet with light, GPS unit). Verify that the sensor wiring has not detached from the datalogger and that the datalogger’s wiring panel has not come apart. Check all datalogger batteries’ voltages and, as necessary, charge depleted batteries (a process that will require about two days per battery).
3. All reference manuals should be re-shelved on their appropriate bookshelf. Other reference materials (e.g., field maps, field sampling locations lists and directions) and extra field data forms need to be filed in their appropriate filing cabinet. Clean the insides and outsides of all vehicles used in the field.
4. Identify and obtain ancillary data. In the notes section of the field forms, make notes on any observed management activities that may impact the current dataset. Also, note any unusual or extreme surface atmospheric conditions that may impact the current dataset.

5. Offload any data files transferred to data shuttles to the project leader's personal computer. The procedure for data offloads depends upon the system (Campbell Scientific's CR10X datalogger or Onset's HOBO datalogger) that generated the data. Detailed instructions for each type of offload follow in subsequent sections of this SOP.
6. At the end of each field sampling session, crew leaders complete a narrative trip report outlining hours worked, field crew members and their responsibilities on the project, and any unique situations/hazards encountered. This information will be used to document the dataset and may be important for data analysis (i.e., it may be the only source of information identifying causes for discrepancies and inconsistencies in the data). The project leader is responsible for ensuring field trip reports are completed and filed in the appropriate folder within the established protocol file structure (i.e., X:\CUPN-MACA IM Projects ...Cave Air Quality).

Campbell Scientific's Storage Module Offload Procedure:

The procedure for transferring data from Campbell Scientific's SM4M storage module to a personal computer follows. This procedure uses version 2.1c of Loggernet.

1. Attach the storage module to your PC. This step requires an additional, intermediate piece of hardware so that the storage module can communicate with the PC. That piece of hardware is the SC532A. This device is a powered CS I/O peripheral to RS-232 interface. First, plug the interface into an outlet. Then, connect the interface to the PC using a 9-pin serial cable. Lastly, connect the storage module to the interface using a second 9-pin serial cable.
2. Launch Loggernet.
3. Click the Storage Module button within Loggernet.
4. Select the SM4M/SM16M tab within the storage module window.
5. Click on the Connect button.
6. Edit the file name and directory for the files about to be uploaded. Since all new files on the storage module will be uploaded, the target directory specified in this step may not be the appropriate directory for all files on the storage module. Therefore, it may be necessary to create a new folder in which to place the uploaded files. When data collection has been completed, the crew leader or project manager should appropriately rename each file (as discussed in step 8) and move the files to the appropriate directory.
7. Click on the Get New button.
8. Uploading will commence. As the upload of one file is completed and the next file is begun, the numeric characters at the end of the file name will be incremented by one. Precedent characters will be unchanged. So, if the first file to be uploaded was user-set to be called "File001.dat," then the second, third, and fourth files would be "File002.dat," "File003.dat," and "File004.dat," respectively. This automated and generic naming convention may make it necessary that the crew leader or project manager rename some or all of the files that are uploaded.
9. Once upload is complete, click on the Disconnect button. Uploaded files are not deleted from the storage module, but may be overwritten as space is needed.
10. Disconnect and stow storage module.
11. Close Loggernet.

Onset's HOBO Shuttle Offload Procedure

The procedure for transferring data from Onset's HOBO shuttle to a personal computer follows. This procedure uses version 4.0 of BoxCar Pro.

1. Attach the data shuttle to your PC. This step requires an interface cable so that the storage module can communicate with the PC. The cable (part number CABLE-HOBO-SHTL) has a stereo jack at one end and a 9-pin serial connector at the other. First, plug the cable's 9-pin connector to a PC, and then connect the cable's stereo jack into the HOBO shuttle.
2. At the end of Step 5, the clock within the HOBO Shuttle will be set to match the time on the PC to which it is attached. The shuttle's time needs to be Local Standard Time (LST). If the PC time is Local Daylight Time (LDT), the shuttle will be set to LDT at the end of Step 5. To avoid the shuttle's being set to LDT, verify that the PC is set to LST. If not, reset the PC clock to LST. Why is this step important? Whenever the shuttle is attached to a HOBO datalogger, the datalogger's time is reset to the time on the shuttle. So, if a shuttle is on LDT, then the datalogger will be placed on LDT as well. In order to keep the datalogger from being placed on LDT, always keep the shuttle on LST.
3. Launch BoxCar Pro.
4. Within the Logger menu, click on HOBO Shuttle Readout.
5. Separate windows will appear as each file on the shuttle is retrieved for offload. Two windows will be launched for each file. The first window is a Save As... window that allows the user to give the file a name and select a directory in which to place the file. Name the file appropriately and select the appropriate directory for file storage. Click Save. The second window will now prompt the user to view, in a graph, plots of the data. The user can select the data to be viewed or press Cancel to view the plots at a later time. The offload process is halted while a plot is being viewed. Either canceling when given the option to view the plots or doing so while viewing the plots takes the user to the next file to be offloaded. Repeat these steps until all files have been offloaded. When all files have been offloaded, a window is launched that presents data on the shuttle's status (i.e. battery charge, shuttle time, etc.). Click OK to close out the offload session.
6. Close BoxCar Pro.

Post-Trip Logistical Checklist

- ☐ 1. Inform surface watch of return.
- ☐ 2. Erase crew sign out from dry board in office.
- ☐ 3. Return keys to appropriate individuals.
- ☐ 4. Review field data forms for completeness and accuracy.
- ☐ 5. As necessary, offload data from Campbell Scientific's SM4M data module.
- ☐ 6. As necessary, offload data from Onset's HOBO shuttle.
- ☐ 7. Examine all supplies and equipment for damage or loss; repair or order replacements as necessary.
- ☐ 8. Remove all batteries from battery-operated equipment if storage will be more than 5 months.
- ☐ 9. Store equipment in proper place.
- ☐ 10. Photocopy field data forms to serve as backups.
- ☐ 11. Project Leader is responsible for filing a field report with the Data Manager.
- ☐ 12. Designated personnel enter data from field forms into database using data entry forms.

Crew Leader's Signature: _____

Date: _____

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 6: Data Management

Version 0.7 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

Introduction

Purpose

This SOP provides instructions for the development, maintenance and distribution of monitoring data associated with the protocol for monitoring cave meteorology throughout the Cumberland Piedmont Network (CUPN). The Cave Meteorology Monitoring Protocol is one of several identified vital signs monitoring protocols currently slated for development by the CUPN.

Per the National Park Service's (NPS) Inventory and Monitoring (I&M) Program, Microsoft Access XP (2002) is the primary software environment being utilized for desktop database applications. All data handling practices from production to distribution and archival should be conducted in accordance with the guidance contained in the CUPN-MACA Data Management Plan (DMP) (Moore et al. 2005). It is the responsibility of the data manager to be thoroughly familiar with the standards and procedures within the DMP and ensure this SOP is updated to reflect any substantive changes made in the DMP. At minimum, it is assumed that individuals involved in the various phases of this project are familiar with the data stewardship roles and commensurate responsibilities contained in Chapter II and Appendix B, of the above referenced DMP. Appendix A of this SOP contains a list of pertinent data stewardship roles for this protocol as defined in the DMP.

All proposed changes to this SOP must be routed through the data manager for approval.

Expected Audience

This SOP is written primarily for data technician(s), the project leader, and the data manager. In all cases, it is intended that this SOP will reduce the overall time required to accomplish the required responsibilities for each of the assigned roles. To accomplish this goal:

- Protocol data managers will want to read the entire SOP like a text book and be familiar with all aspects of the document. Data managers should be looking for ways to

improve the system, but must first possess a working knowledge of the system being used.

- Protocol project leaders should also be familiar with this SOP, paying particular attention to the data flow and handling procedures. Project leaders are responsible for understanding and fulfilling the data stewardship responsibilities assigned their role, as well as ensuring that anyone under their supervision understands and fulfills their assigned responsibilities.
- Data Technicians need not be familiar with all aspects of this SOP but should instead focus on sections related to their area(s) of responsibility (e.g., data entry, verification).

Cave Meteorology Database - Metadata

Metadata, or data about the data, include two basic categories: (1) the data structure information or data dictionary, and (2) data that describe the environment surrounding the purpose of the study. The data dictionary includes information such as field name, field type, field length, etc. (see Appendix B). The second category of metadata includes, for example, the contact information of the sample collector (name, address, phone number, etc.), or information about the location where the data were collected. These are metadata. The “real” data may be, for example, the temperature and relative humidity values at a particular plot—that are of no value unless accurate metadata are associated with this attribute data (e.g., where the plot is located). Thus, the importance of accurate metadata cannot be overemphasized.

Because of the importance of metadata, much effort has been exerted both by the NPS and the developers of this project to insure data are properly documented. The NPS Metadata Tools & Editor (MTE) is a custom software application for authoring, editing, and managing National Park Service (NPS) metadata. It can operate as either an extension to ArcCatalog or as a standalone desktop application. The MTE is intended to be the primary editor for metadata that will be uploaded to the NPS Data Store and produces XML metadata based on the NPS Metadata Profile. Metadata editing is accomplished with editing stylesheets that transform an XML metadata file into an editable record.

Because this project contains information that can be considered protected or sensitive (i.e., cave locations), authorization must be obtained, beginning with the CUPN co-coordinator, before any data products are released and/or posted in a location where the public may potentially gain access. Refer to Chapter IX of the CUPN-MACA Data Management Plan (Moore et al. 2005) for further guidance regarding the release of information.

Cave Meteorology Database

The general data model for cave meteorology monitoring consists of: (1) metadata (described above) and (2) field collection data. Proper linking of the two is critical to effective long-term monitoring and analysis of cave meteorology data, and provides park managers and policy makers with information necessary to make informed decisions regarding the use and conservation of the park’s natural resources.

Cave Meteorology Data Model

Table structures and relationships for the cave meteorology monitoring protocol were developed utilizing the Natural Resource Database Template (NRDT) version (3.0). The I&M Program developed the NRDT as a standard Microsoft Access database core for natural resource inventory and monitoring project datasets. It is comprised of a set of relational database tables that parks and networks can use as a standardized yet flexible database core to develop applications to capture, manage and share natural resource inventory and monitoring data. For more information on the NRDT the reader is referred to the NRDT Version 3 documentation (Washington Support Office, I&M Program 2004b).

At its core, NRDT establishes a one-to-many relationship between locations and events. This creates some difficulty when adapting cave protocols to the NRDT because a location cannot be geographically “pinpointed” in the same manner as surface locations with currently available technology. As such, **Location_ID** references the cave entrance (i.e., the closest point where geographic coordinates can be collected). Within the caves, the true sampling locations (i.e., plots, cross-sections, etc) are referenced from permanent landmarks via bearing, elevation, and distance. Refer to the appropriate SOP regarding selection and identification of landmarks. Thus each “location” within the cave meteorology data model has multiple sub-locations where sampling actually takes place. **Event_ID** represents many multiple types of events such as collection of temp/Rh data within a “seasonal” sampling grid, download and/or servicing of HOBO data loggers, or mapping and/or downloading airflow data from a cave cross-section.

In addition to utilizing the NRDT, CUPN is adhering to the recommended database naming conventions developed by the I&M Program (Washington Support Office, I&M Program 2004a) where possible to aid in consistency between protocols within the CUPN and hopefully other networks.

Database Structure

The cave meteorology monitoring protocol includes three modes of field data collection. These include: “seasonal” spatially distributed temperature and relative humidity data (Campbell data); long-term, automated temperature and relative humidity data (HOBO data); and air velocity

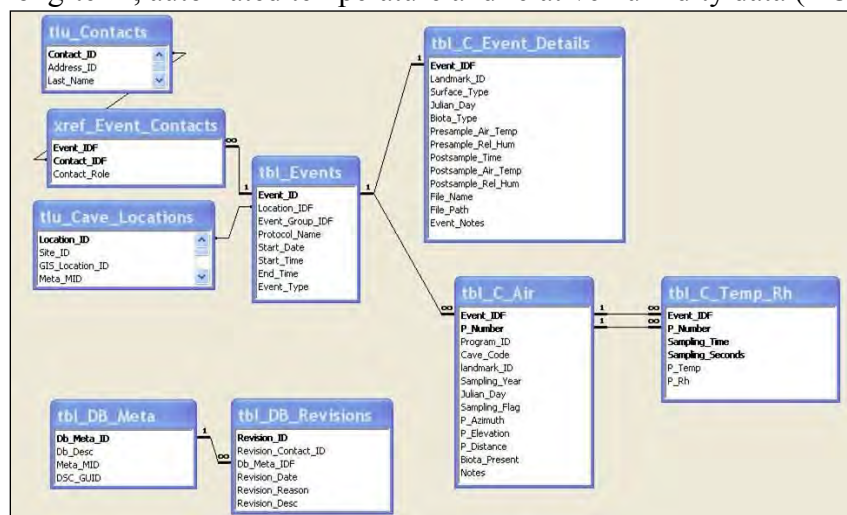


Figure 20. Relationships Diagram for the Campbell Portion of the Cave Meteorology Monitoring Protocol.

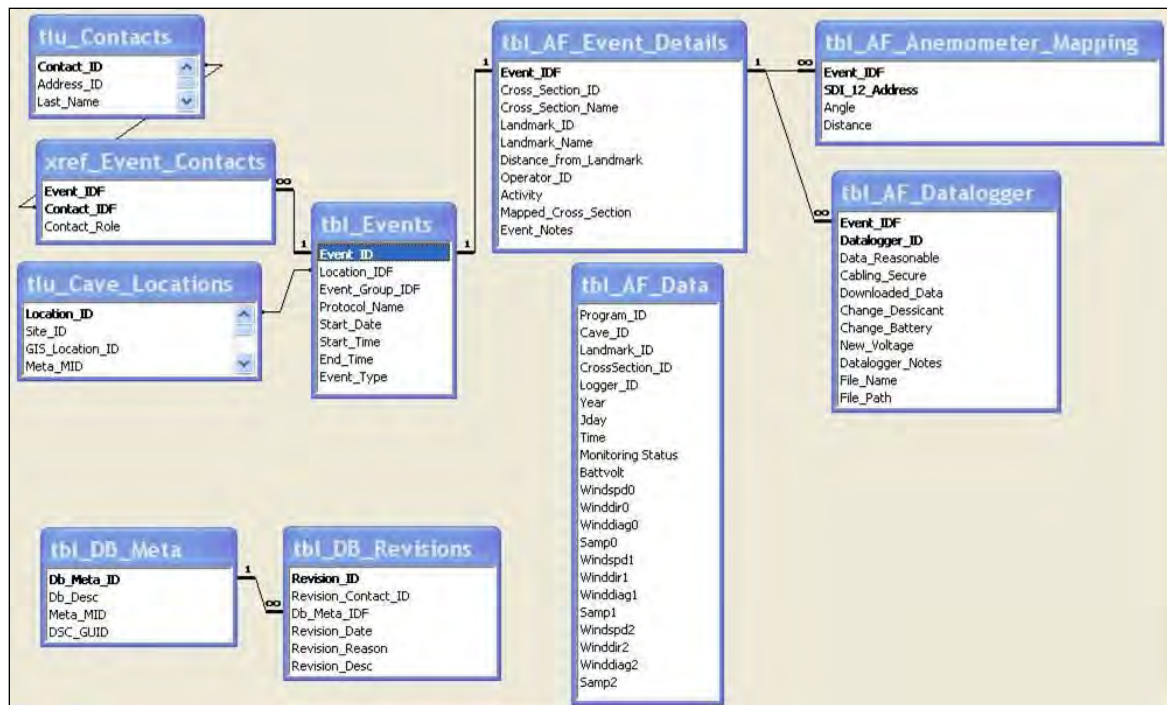


Figure 18. Relationships Diagram for the Air Flow Portion of the Cave Meteorology Monitoring Protocol.

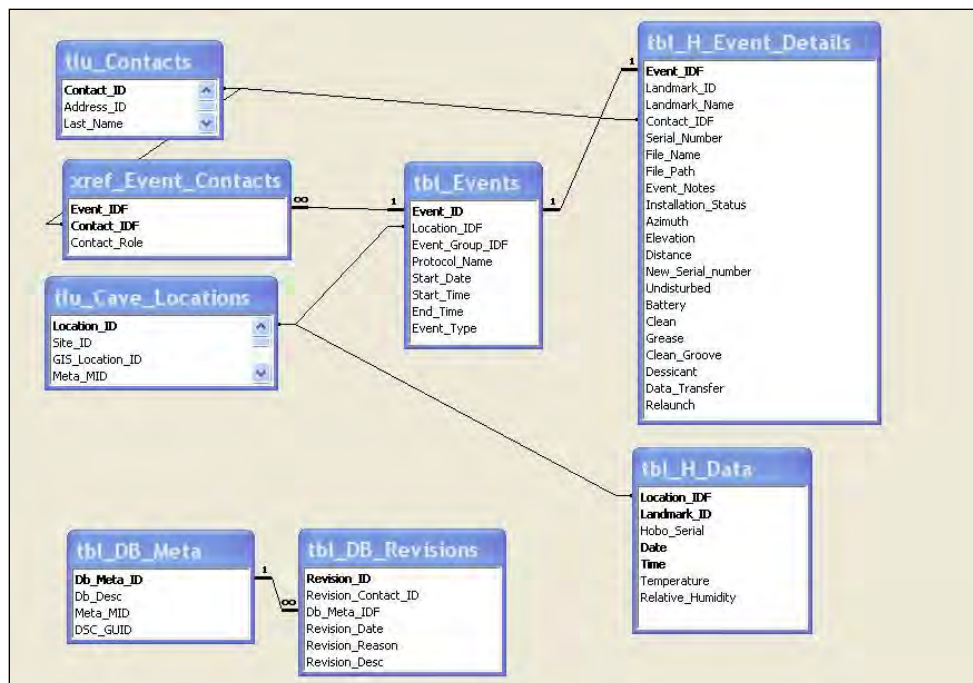


Figure 22. Relationships Diagram for the HOBO Portion of the Cave Meteorology Monitoring Protocol.

within a cave cross section (air flow data). Refer to SOP 4a and 4b for specifics regarding each of these methodologies. *Currently* data collected by the three methodologies will be stored in tables in the same back-end database (Cave_Air_vX.X_be.mdb), where “vX.X” represents the current file version. Figures 20-22 display relationship diagrams for each of the three methods, all of which are contained within Cave_Air_vX.X_be.mdb. Refer to Appendix B for field description and data type information for each of the tables located within this file.

The associated data entry forms, queries, import/export routines, etc. for each of the three methodologies are also located within the same front-end database (Cave_Air_vX.X.mdb). Most users (i.e., those entering, importing, or exporting data) will perform all operations via the front-end file. In addition to the front-end and back-end files already noted, a third file (Common_Lookups_vX.X.mdb), must also be linked to make the application complete. As its name implies this third file contains data shared across multiple protocols within the CUPN, including cave names and contacts.

Data Flow and Data Entry

Data Flow

Periodically observers will conduct field sampling within specified caves per the guidance found in the field sampling SOPs for this protocol. Event specific metadata (e.g., date, crew members, cave, etc.) are recorded on a paper field form. Once within the cave, the actual field data is collected with the aid of automated dataloggers. Thus, two types of data (manual and digital) are collected and transported to the office where they must be entered and properly linked within the database.

For this protocol, the investigators have prescribed that the data are to be uploaded in the field to a storage module for transport to the office. The storage module is a small, robust device used to house datalogger data. It is the responsibility of the field crew leader to ensure this upload is conducted correctly. In addition, the field crew leader will recheck the event data forms for completeness and accuracy, prior to leaving the field.

It is the responsibility of the crew leader to submit the event data forms and storage module to the project leader upon returning from the field. Currently, the project leader is responsible for data entry of the field form and import of the automated data into the database.

After certifying the validity of the data content for each event, the project leader will contact the data manager who will certify the format and overall reliability of the data, prior to appending and/or archiving validated datasets on the CUPN file server.

Data Entry

Prior to commencement of database use, a user (e.g., data technician, project leader, crew leader, crew member, etc.) will have reviewed this SOP and received hands-on training from the project leader and/or data manager in the use of the protocol-specific database and demonstrate a level of competency and understanding of the data processing steps.

Use of programmatic quality assurance checks has been incorporated into the data entry forms where possible. For example, look-up tables containing program specific data (e.g., caves and

contacts) are utilized to greatly limit the possibility of entering incorrect values in these fields. It is anticipated that as testing and development of this database progresses, additional measures will be identified and incorporated into data entry forms.

Data entry mimics the order in which data are collected in the field. Specifically metadata gathered in the field (e.g., cave, date, and observers) are the first phase of data entry utilizing the forms in Figures 23-25. After entering an event the data technician should verify that all database entries match the values on the original field form before proceeding further.

Figure 23. Data Entry Form for the Campbell Portion of the Cave Meteorology Monitoring Protocol.

Figure 19. Data Entry Form for the Airflow Portion of the Cave Meteorology Monitoring Protocol.

HOBO Temperature/RH Data

HOBO Pro RH/Temp Datalogger - Site Setup and Maintenance Field Observer Form

Cave name: Event Type:

Landmark Name: Landmark ID:

Crew Member:

HOB0 Serial Number: pre-existing or new installation

Date (mm/dd/yyyy): Time (LST):

Datalogger Installation status (check one):

☒ Installed datalogger today.

☐ This datalogger is being replaced today.

☐ Servicing existing datalogger. (check box if answer is yes)

☐ Datalogger undisturbed?

☐ Change battery?

☐ Cleaned drying?

☐ Datalogger Serial Number: (replacement datalogger)

☐ Cleaned drying probe?

☐ Dried and drying?

☐ Replaced desiccant?

☐ Data transfer successful?

☐ Datalogger reattached?

Notes:

Office Use Only: File Name: Browse Import *.dat File Close

Record: 1 of 1

Figure 20. Data Entry Form for the HOBO Portion of the Cave Meteorology Monitoring Protocol.

Once these data are verified by the data entry technician, the next phase of data entry is to import the digital file collected on the datalogger in the field. Note, this file should have already been downloaded into an accessible folder. Click browse on the data entry form, locate the appropriate file, and click the import *.dat file button. The data entry technician will be provided opportunity to review the file and cancel the operation if needed.

Data Verification

As noted, the majority of field data collection will be collected digitally, thus greatly reducing the possibility for manual transcription errors. However, this puts greater importance on ensuring all equipment is functioning and calibrated properly and that all procedural steps in the field methods are followed.

Verification includes checking the accuracy of computerized records against the original source (i.e., the paper field forms). As noted earlier, all manually entered data must be verified immediately following record entry. While the goal of data entry is to achieve 100 percent correct entries, this is rarely accomplished every time. Thus, in addition to this initial check the data entry technician will be afforded a second opportunity to verify the event metadata against the values within the import file from the datalogger before the importation process is complete. This provides a second check of these values and also an opportunity to ensure the correct file was selected for importation.

The primary goal of data entry verification is to determine where errors are being introduced into the system. Each error found will, of course, be corrected, but will additionally be cataloged to find methods for eliminating that specific type of error during subsequent sampling periods. For example, if data entry of a certain field is more prone to entry errors, a more stringent computer

validation method and/or field method will be created to reduce the probability of that error occurring in the future. Once the computerized data are verified as accurately reflecting the original field data and validation is complete, the project leader can submit original field forms for archival. The electronic version of the data is used for all subsequent data activities.

Data Validation

In addition to data validation described above, the project leader must also review and validate the data after verification is complete. Validation procedures seek to identify data values that are not logical. The primary question throughout the validation process should be “Do these data make sense?” As such, data validation will be conducted by the project leader, who is an authority on the methodologies and “acceptable” data values.

During the entry, verification, and validation phases, the project leader is responsible for the data. The project leader must assure consistency between field data forms and the database by noting how and why any changes were made to the data on the original field forms. In general, changes made to the field forms should not be made via erasure, but rather through marginal notes (preferred) or attached explanations. Once validation is complete, the dataset should be turned over to the data manager for archival on a routine basis.

Data validation procedures are currently (03/12/2007) still in development for this protocol. The data manager and project leader will develop validation procedures such as max/min values, means, etc. to address the unique validation needs of the dataset. These will be developed prior to full implementation of the protocol.

Database Administration

Data Maintenance

Datasets are rarely static. They often change through additions, corrections, and improvements made following the archiving of a dataset. There are three main caveats to this process:

1. Only make changes that improve or update the data while maintaining data integrity.
2. Once archived, document any changes made to the dataset.
3. Be prepared to recover from mistakes made during editing.

Any editing of archived data is accomplished jointly by the project leader and data manager. Every change must be documented in the edit log and accompanied by an explanation that includes pre- and post-edit data descriptions.

Data Organization

CUPN has established a template directory structure, composed of seven folders and four subfolders for each vital sign monitoring project (Figure 26). Project files which are being modified, considered draft, and/or certain files currently in use (e.g., a copy of the field data form) should reside within this directory. A similar directory structure will contain archived files. Both the working and archive directories are accessible via the MACA Local Area

Network (LAN), and located on the CUPN file server. Access permissions are maintained by the data manager(s) and/or MACA Information Technology (IT) Staff.

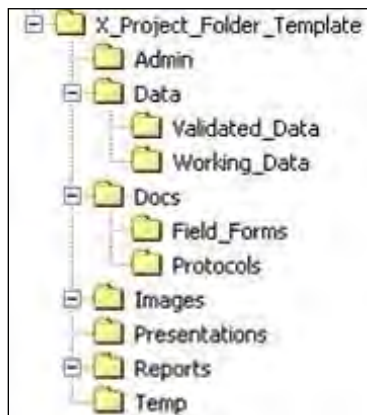


Figure 21. CUPN Project Directory Structure

Typically data tables utilized for data entry and validation for CUPN monitoring protocols reside within the “Working_Data” folder. Once data in these tables are validated by the project leader, the data manager will append the records to the data tables in the “Validated_Data” folder and the “working” data tables are purged. As indicated, the data tables containing the master protocol-specific data for the project are contained in the “Validated_Data” folder. These data have been validated and are available as read-only except to CUPN data managers and co-coordinators.

However, in consultation with the project leader it has become evident that the cave meteorology monitoring protocol has unique storage needs that may not be accommodated well, while working across the MACA LAN. As such, a workable scenario that ensures accessibility, security, and recovery of datasets remains to be formulated for this protocol.

Data Security and Integrity

As many different users will be accessing the database, it is imperative that data are available, as well as protected from inadvertent changes. Although MS Access provides a means for allowing User-Level Securities to different groups of uses, the data managers have determined that it will be more effective to create user groups within the local area network operating system that will have different security levels. Currently two levels of users are given different sets of permissions. CUPN data managers and co-coordinators have all permissions, including insert, delete, and modify for all folders residing on the CUPN file server. Project leaders, data technicians, etc. have the same permissions as program data managers except for read-only permission to the shared data tables, validated data, and archived data. Additional user groups will be evaluated on an “as need basis.”

Version Control

Prior to any major changes of a dataset, a copy is stored with the appropriate version number. This allows for the tracking of changes over time. With proper controls and communication, versioning ensures that only the most current version is used in any analysis. Versioning of

datasets is handled via a two digit numeric value (e.g., Cave_Air_v1.0_be.mdb). Once archived, an eight digit date value is also appended to the end of the file name (e.g., Cave_Air_v1.0_be_20070312.mdb) by adding an three digit number to the file name, with the first version being numbered 001. Each new version is assigned a sequentially higher number. Frequent users of the data are notified of the updates, and provided with a copy of the most recent archived version as requested.

Data Logs and Backups

Once the data are archived, any changes made to the data must be documented in an edit log. From this point forward, original field data forms should not be altered. Field forms can be reconciled to the database through the use of the edit log. Secure data archiving is essential for protecting data files from corruption. Once a dataset has passed the specified QA/QC procedures, the data manager will make a formal entry in the I&M Dataset Catalog. Subsequently, an electronic version of the dataset is maintained in a read-only format on the program server. Incremental or differential tape backups of all project databases are regularly conducted. Backup copies of the data are maintained in a secure alternate location.

Data Availability

In addition to the “standardized” data dissemination strategies noted in Chapter IX of the DMP, data will be made available for research and management applications on request (per the framework established in the DMP). Data requests should be directed to the CUPN network co-ordinators.

Literature Cited

- Moore, W. J., R. Byrd, and T. Leibfreid. 2005. Data management plan for the Cumberland Piedmont Network and Mammoth Cave National Park Prototype monitoring program. USDI National Park Service. Mammoth Cave, KY. 81pp.
- Washington Support Office, Inventory and Monitoring Program. 2004a. Recommended naming standards for inventory and monitoring databases. Version 3, February 2005. USDI National Park Service, Online (http://science.nature.nps.gov/im/apps/template/IM_DB_Naming_Recs_v3.pdf). Accessed 05 August 2005.
- Washington Support Office, Inventory and Monitoring Program. 2004b. Natural Resource Database Template Version 3 Documentation. National Park Service. Fort Collins, CO. 21 pg.

Appendix A: Data Stewardship Roles for Cave Meteorology Monitoring at Mammoth Cave National Park

This appendix contains a list of pertinent data stewardship roles for this protocol as defined in the DMP. For a comprehensive list of responsibilities assigned to each role refer to Appendix B, “Data Stewardship Roles and Responsibilities”, of the CUPN-MACA Data Management Plan (DMP) (Moore et al. 2005).

Role	Individual(s)/Entities	Duty Station / Title	Contact
Project Crew Member	TBD	MACA / WKU Biology Dept. Student Intern #1	(270) 745-4856
	TBD	MACA / WKU Biology Dept. Student Intern #2	(270) 745-4856
Project Crew Leader	Johnathan Jernigan	MACA / Physical Scientist	(270) 758-2146
Data Technician	Variable (dependent on availability and training). Ideally this individual will be someone who was involved in the collection of the data they will be processing.	MACA / Variable	Multiple
Information Technology Specialist	Pat Price	MACA / Supervisory IT Specialist	(270) 758-2130
Project Leader/Resource Specialist	Johnathan Jernigan	MACA / Physical Scientist	(270) 758-2146
GIS Specialist	Lillian Scoggins	MACA / GIS Specialist	(270) 758-2149
Data Manager	Bill Moore	MACA / Data Manager	(270) 758-2161
Curator	Brenda Wells	MACA / Ecological Assistant	(270) 758-2134
Coordinator	Steve Thomas	MACA / Network Co-coordinator	(270) 758-2144
Data Manager (National Level)	Margaret Beer	Fort Collins, CO / NRP Data Manager	(970) 267-2168
End Users (managers, scientists, publics)	Multiple Entities	Multiple	Multiple

Appendix B: Table and Field Descriptions – Cave Meteorology DB (v1.0)

Database Dictionary

Cave_Air_v1.0_be_20061004

Documentation Date: 3/15/2007

*** Refer to Appendix D of the CUPN-MACA Data Management Plan (Moore et al. 2005) for descriptions of linked tables.**

Table *tbl_AF_Anemometer_Mapping*
Description *Anemometer head mapping data*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Angle	-no description-	dbSingle	4
Distance	-no description-	dbSingle	4
Event_IDF	-no description-	dbGUID	16
SDI_12_Address	-no description-	dbByte	1

Table *tbl_AF_Data*
Description *Airflow datalogger data extracted from file*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Winddir0	-no description-	dbDouble	8
Landmark_ID	Landmark ID	dbLong	4
Battvolt	-no description-	dbDouble	8
Monitoring Status	-no description-	dbLong	4
Time	-no description-	dbLong	4
Jday	-no description-	dbLong	4
Year	-no description-	dbLong	4
CrossSection_ID	Cross-section ID	dbLong	4
Winddiag0	-no description-	dbDouble	8
Cave_ID	Cave ID (numeric only)	dbLong	4
Logger_ID	Identifies which datalogger generated the dbLong file (Datalogger 1=210, Datalogger 2=543)		4
Windspd2	-no description-	dbDouble	8
Windspd0	-no description-	dbDouble	8
Samp2	-no description-	dbDouble	8
Program_ID	Collection 'Type' (101=air temp/Rh; 102=air velocity, data logger1; 103=air velocity, data logger2);used to identify raw data files.	dbLong	4

Winddir2	-no description-	dbDouble	8
Samp1	-no description-	dbDouble	8
Winddiag1	-no description-	dbDouble	8
Winddir1	-no description-	dbDouble	8
Windspd1	-no description-	dbDouble	8
Samp0	-no description-	dbDouble	8
Winddiag2	-no description-	dbDouble	8

Table *tbl_AF_Datalogger*
Description *Seasonal equipment setup, disassembly and maintenance data*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Datalogger_ID	Datalogger 1 or 2	dbByte	1
Cabling_Secure	Datalogger Maintenance-Were instrumentdbBoolean supports and cabling secure on datalogger?		1
Change_Dessicant	Datalogger Maintenance-Was dessicant dbBoolean changed?		1
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
Data_Reasonable	-no description-	dbBoolean	1
New_Voltage	Datalogger Maintenance-If battery dbText changed, what was the new voltage? (should be approx. 13.0-13.1)		50
Datalogger_Notes	General notes on datalogger	dbMemo	0
File_Path	Raw data File Directory (when loaded)	dbMemo	0
File_Name	Raw Data File Name (mmddyy_day's dbText dataset #)		50
Change_Battery	Datalogger maintenance-Was battery dbBoolean changed?		1
Downloaded_Data	Datalogger Maintenance-Were data dbBoolean downloaded from datalogger?		1

Table *tbl_AF_Event_Details*
Description *MA. Sampling event details for airflow data*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
Operator_ID	Contact ID of the person operating the anemometers	dbGUID	16
Cross_Section_ID	Cross-Section ID (manual entry)	dbInteger	2
Cross_Section_Name	Cross-Section Name (manual entry)	dbText	50
Landmark_Name	Cave Landmark reference point for plot/point (manual entry)	dbText	50
Distance_from_Landm	Distance from Landmark (m)	dbSingle	4
Activity	Equipment Setup or Equipment Disassembly	dbByte	1
Mapped_Cross_Sectio	Mapped cross-section today?	dbBoolean	1
Event_Notes	MA. General notes on the event (Ev_Notes)	dbMemo	0
Landmark_ID	Cave Landmark reference point for plot/point (manual entry)	dbInteger	2

Table *tbl_C_Air*
Description *Campbell cave air temperature and relative humidity data per point*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
P_Azimuth	Plot or point azimuth from landmark	dbSingle	4
Sampling_Year	Year data collected (yyyy)	dbInteger	2
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
P_Number	Individual Sampling Location ID (plot or point) where data collected	dbInteger	2
Program_ID	Collection 'Type' (101=air temp/Rh; 102=air velocity, data logger1; 103=air velocity, data logger2)	dbInteger	2
Julian_Day	Julian Day data collected (day = 1-365)	dbInteger	2
Cave_Code	Campbell Data Logger Cave Identifier	dbInteger	2
P_Elevation	Plot or point elevation from landmark	dbSingle	4
P_Distance	Plot or point distance from landmark (meters)	dbSingle	4
Biota_Present	Biota Type (e.g., cricket, beetle, bat), Present?	dbInteger	2
landmark_ID	Cave Landmark reference point for	dbInteger	2

	plot/point		
Notes	Notes about that specific plot number	dbMemo	0
Sampling_Flag	Sampling Flag; 1=valid sample, 0=invalid	dbInteger	2

Table *tbl_C_Event_Details*
Description *MA. Sampling event details.*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
File_Name	Raw Data File Name (mmddyy_day's dataset #)	dbText	50
Biota_Type	Corollary biota type (e.g., cricket, beetle, bat, or none)	dbText	50
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
Landmark_ID	Cave Landmark reference point for plot/point (manual entry)	dbInteger	2
Julian_Day	Julian Day data collected (day = 1-365) (manual entry)	dbInteger	2
Presample_Air_Temp	Surface Air Temperature, pre-sample (C)	dbSingle	4
Presample_Rel_Hum	Surface Relative Humidity, pre-sample (%)	dbSingle	4
Postsample_Time	Time when post sample air, relative humidity values collected	dbDate	8
Postsample_Rel_Hum	Surface Relative Humidity, post-sample (%)	dbSingle	4
Event_Notes	MA. General notes on the event (Ev_Notes)	dbMemo	0
Surface_Type	Surface Type (C=Ceiling, W=Wall, F=Floor)	dbText	50
File_Path	Raw data File Directory (when was loaded)	dbMemo	0
Postsample_Air_Tem	Surface Air Temperature, post-sample (C)	dbSingle	4

Table *tbl_C_Logger*
Description *Table to hold temporarily data from data logger file*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Sampling_Seconds	Sampling time seconds (ss.ss)	dbSingle	4
Sampling_Flag	Sampling Flag; 1=valid sample, 0=invalid	dbInteger	2
P_Azimuth	Plot or point azimuth from landmark	dbSingle	4
Cave_Code	Campbell Data Logger Cave Identifier	dbInteger	2

landmark_ID	Cave Landmark reference point for plot/point	dbInteger	2
Sampling_Year	Year data collected (yyyy)	dbInteger	2
Sampling_Time	Sampling time (hhmm)	dbInteger	2
P_Number	Individual Sampling Location ID (plot or point) where data collected	dbInteger	2
P_Elevation	Plot or point elevation from landmark	dbSingle	4
P_Distance	Plot or point distance from landmark (meters)	dbSingle	4
P_Temp	Plot or point temperature (Celsius)	dbSingle	4
P_Rh	Plot or point relative humidity (%)	dbSingle	4
Program_ID	Collection 'Type' (101=air temp/Rh; 102=air velocity, data logger1; 103=air velocity, data logger2)	dbInteger	2
Julian_Day	Julian Day data collected (day = 1-365)	dbInteger	2

Table *tbl_C_Temp_Rh*
Description *Cave air temp/rh by time*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
P_Temp	Plot or point temperature (Celsius)	dbSingle	4
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
Sampling_Seconds	Sampling time seconds (ss.ss)	dbSingle	4
P_Rh	Plot or point relative humidity (%)	dbSingle	4
P_Number	Individual Sampling Location ID (plot or point) where data collected	dbInteger	2
Sampling_Time	Sampling time (hhmm)	dbInteger	2

Table *tbl_Db_Meta*
Description *M. Database description and links to I&M metadata tools.*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Db_Meta_ID	M. Local primary key (Db_Meta_ID)	dbGUID	16
Db_Desc	M. Description of the database purpose (Db_Desc)	dbMemo	0
Meta_MID	M. Link to NR-GIS Metadata Database (Meta_MID)	dbGUID	16
DSC_GUID	M. Link to I&M Dataset Catalog desktop	dbGUID	16

metadata tool (DSC_GUID)

Table *tbl_Db_Revisions*
Description *M. Database revision history data.*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Revision_ID	M. Database revision (version) number or dbText code (Rev_ID)		50
Db_Meta_IDF	M. Link to tbl_DB_Meta (Db_Meta_ID)	dbGUID	16
Revision_Contact_ID dbGUID	MA. Link to tlu_Contacts (Rev_Cnt_ID)		16
Revision_Date	M. Database revision date (Rev_Date)	dbDate	8
Revision_Desc	M. Revision description (Rev_Desc)	dbMemo	0
Revision_Reason	M. Reason for the database revision (Rev_Reason)	dbMemo	0

Table *tbl_Events*
Description *M. Sampling events.*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Event_Type	Type of Event being entered (i.e., Airflow, HOBO or Campbell). Autopopulated based on which 'event'	dbText	10
Location_IDF	M. Link to tbl_Locations (Loc_ID)	dbGUID	16
Event_ID	M. Event identifier (Event_ID)	dbGUID	16
End_Time	Ending time for the event	dbDate	8
Protocol_Name	M. The name or code of the protocol governing the event (Protcl_Nam)	dbText	100
Start_Time	MA. Starting time for the event (Start_Time)	dbDate	8
Start_Date	M. Starting date for the event	dbDate	8
Event_Group_IDF	MA. Link to tbl_Event_Group	dbGUID	16

Table *tbl_H_Data*
Description *Hobo data with cave and landmark info*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Location_IDF	-no description-	dbGUID	16

Landmark_ID	-no description-	dbInteger	2
Hobo_Serial	-no description-	dbText	50
Date	-no description-	dbDate	8
Time	-no description-	dbSingle	4
Temperature	-no description-	dbSingle	4
Relative_Humidity	-no description-	dbSingle	4

Table *tbl_H_Datalogger*
Description *Hobo data from file*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Date	-no description-	dbDate	8
Temperature	-no description-	dbSingle	4
Relative_Humidity	-no description-	dbSingle	4
Time	-no description-	dbSingle	4

Table *tbl_H_Event_Details*
Description *MA. Sampling event details for hobo data*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Elevation	-no description-	dbInteger	2
Event_IDF	Foreign Key, tbl_Events	dbGUID	16
Landmark_ID	Cave Landmark reference point for plot/point (manual entry)	dbInteger	2
Landmark_Name	-no description-	dbText	50
Clean_Groove	-no description-	dbBoolean	1
Serial_Number	-no description-	dbText	50
File_Name	Raw Data File Name (mmddyy_day's dataset #)	dbText	50
File_Path	Raw data File Directory (when was loaded)	dbMemo	0
Event_Notes	MA. General notes on the event (Ev_Notes)	dbMemo	0
Installation_Status	Datalogger installation status: Installed, Service or Replaced	dbByte	1
Azimuth	-no description-	dbInteger	2
New_Serial_number	-no description-	dbText	50
Undisturbed	-no description-	dbBoolean	1

Battery	-no description-	dbBoolean	1
Clean	-no description-	dbBoolean	1
Relaunch	-no description-	dbBoolean	1
Contact_IDF	Contact_ID of the person acting as a Crew member	dbGUID	16
Dessicant	-no description-	dbBoolean	1
Data_Transfer	-no description-	dbBoolean	1
Distance	-no description-	dbInteger	2
Grease	-no description-	dbBoolean	1

Table *xref_Event_Contacts*
Description *O. Cross-reference table between event groups and contacts.*

FIELD NAME	FIELD DESCRIPTION	FIELD TYPE	FIELD WIDTH
Contact_IDF	Link to tlu_Contacts	dbGUID	16
Contact_Role	Role of contact for specified Event Group	dbText	20
Event_IDF	Link to tlu_Event_Group	dbGUID	16

Appendix C: QA/QC Process Flow for Cave Meteorology Monitoring (*In Development*)

<u>QA/QC Procedure Name</u>	<u>Schedule</u>	<u>Description of Procedure</u>	<u>Responsible Entity</u>	<u>Response</u>
Immediate Verification	Before leaving cave	Crew leader and crew members will verify all data on their field forms pertaining to the cave and/or region sampling effort.	Crew Leader	If there are blank or incorrect entries they will be corrected immediately. If a procedural change or new datasheet format could prevent future mistakes, the suggestion will be annotated in the notes.
Field Notes Review	Immediately after returning from the field	After the crew returns from the field the crew leader will assure that all field data forms are accounted for and complete.	Crew Leader	Make sure all data have been entered and all data sheets are accounted for.
Field Form to Computer Form Verification	As entered	The person who enters the data into the computer from the field datasheets explicitly compares the paper datasheet with the data on the computer screen to verify correct data entry before advancing to the next record.	Data Technician	Make corrections immediately and, if the errors could have been prevented by changing a process or computer form tell the data manager.
Hardcopy-to-Digital Verification	As soon as practicable, following previous step	Verify manual photo data form totals with computer photo form totals, via Photo Summary button. Verify all caves have been entered and photo record has been entered for each plot, via Data Entry Summary button.	Data Technician	Record any data entry errors, abnormal values, or other discrepancies found in dataset via a standardized form. Make appropriate corrections at time of check, and submit form to project leader.
Data Validation	As soon as practicable, following previous step	Project leader reviews data for logic errors or inconsistencies, make recommendations for automated approaches to data manager.	Project Leader and Data Manager	Record any inconsistencies and import error messages. Correct problems and/or change process as needed. Provide feedback to data technicians and crew members as appropriate.
Data Documentation and Dissemination	At least annually, but prior to any data releases	Ensure dataset is fully documented and sensitive information is flagged	Data Manager, GIS Specialist and Project Leader	

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 7a: Analysis of Air Temperature and Relative Humidity Data

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP outlines the data flow and expected analyses of the air temperature and relative humidity component of the cave meteorology monitoring data collected within the Cumberland Piedmont Network (CPN). The monitoring questions and subsequent analysis of the supporting data address issues related to status and trends in air temperature and relative humidity in caves. The status and trends of these parameters likely produce impacts on biotic and abiotic components of cave systems. Data collected through this protocol may be used to assess the impacts of management activities, such as cave entrance modification, and variable disturbance from cave tours, upon cave meteorology. The sampling design provides an assessment of spatial distribution of air temperature and relative humidity within a cave room along a surface of interest. These spatial data may be analyzed to generate the mean air temperature and relative humidity for the cave space sampled. Additionally, the standard deviation may be computed for the cave space, providing, when coupled with the mean values, indices for spatial heterogeneity in air temperature and relative humidity within the cave space. These data may be collected over multi-year scales. When collected over long-term (as well as short-term) time scales, these data may be used to evaluate the impacts of management actions upon air temperature and relative humidity (and impacts on air temperature and relative humidity could have subsequent impacts on biotic and abiotic cave components). Monitoring questions will be addressed using a combination of summary and descriptive statistics, graphic analysis, and multivariate comparative and correlative analysis.

The protocol was designed to answer the following monitoring questions:

1. What is the status of air temperature and relative humidity within a given cave space?
2. What is the trend over time in air temperature and relative humidity for these cave spaces?
3. What is the spatial distribution of air temperature and relative humidity for a given cave space and does this distribution produce a response in selected biota that may be present?
4. How do management actions impact values in air temperature and relative humidity within a given cave space?

Data Flow

The data manager will work with the project leader to ensure that data are regularly verified and rolled up into a master copy of the dataset in the “DBMS_Master” folder for this protocol (i.e., X:\CUPN-MACA IM Projects...\CaveAirQuality\DBMS_Master). This folder is reserved for datasets that have already been validated, will no longer change, and with the exception of the data manager, is available to Cumberland Piedmont Network-MACA Prototype (CUPN-MACA) staff with read-only access privileges. This ensures that once data are validated, the dataset remains accessible to staff while being secure from accidental or undocumented changes. This copy of the dataset, which is in .mdb format, should be utilized by CUPN-MACA staff for all analyses.

The development of basic queries and summary reports in MS Access will be utilized to automate and thus streamline the data analysis and reporting workload, as appropriate. In consultation with the project leader, the data manager will develop queries (and accompanying summary reports) that will address basic statistical questions including:

- Spatial distribution of air temperature and relative humidity (and, where appropriate, its correlation to spatial distribution of biotic cave components)
- Variability in air temperature and relative humidity indices for a sampled cave space
- Modeled “continuous” time series for
 - Air temperature mean
 - Air temperature standard deviation (variability index)
 - Relative humidity mean
 - Relative humidity standard deviation (variability index)

These are basic questions which the project leader anticipates asking on an irregular, but frequent basis in order to provide various “snapshots” of the current dataset. It is anticipated the results of these queries will be relied upon heavily for annual reporting requirements to the parks, as well as internal reports generated for CUPN-MACA staff and cooperators. The data manager will construct these queries and reports within the front-end of the current version of the protocol’s MS Access database stored in the X:\CUPN-MACA IM Projects . . . \CaveAirQuality\DBMS_Forms folder, which can be linked to the appropriate data tables on the MACA server. Note: This front-end database can be copied to the project leader’s workstation in order to increase performance. However, the working and master back-end databases should remain on the MACA server in their respective folders at all times.

In instances where the statistical questions become increasingly complex, such as the generation of modeled data for air temperature and relative humidity, data will need to be exported out of the relational MS Access database to commercial off-the-shelf statistical packages. CUPN-MACA staff primarily utilize SigmaStat, Systat, and SigmaPlot for frequency distribution plots, test for normality, analysis of variance, time series analysis, etc. In these instances, the data manager will work with the project leader and other CUPN-MACA staff to format data for export. In general, these data will be formatted based on parameters provided to the data

manager via a make-table query in MS Access. The generated table will be exported in comma delimited ASCII text format.

Data Analysis

Data in comma delimited ASCII text format are readily imported into statistical analysis software used at CUPN-MACA (e.g., SigmaStat and SigmaPlot). The sequence of steps for data import within SigmaStat and SigmaPlot are:

1. Launch SigmaStat or SigmaPlot.
2. Click on File to view the File menu.
3. Select Import from the File menu.
4. A window will open in which the user can select the appropriate file type and the file to be imported. There will be a drop-down list from which the appropriate file type may be selected. Select "Plain Text." Then, navigate to the appropriate folder and select the desired file.
5. Now, a new window is launched in which the field format must be indicated. Select "Delimiter" and the comma from the associated drop-down list. Click on "Import."

We anticipate that analyses will explore the behavior of cave meteorological sample parameters over time. Data managers will provide make-table queries within the database or, upon request, data tables that include means for these parameters. These data will be imported into SigmaStat or SigmaPlot for higher level statistical analyses (i.e. t-tests and ANOVA).

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 7b: Analysis of Cross-Sectional Air Velocity Data

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP outlines the data flow and expected analyses of the air velocity component of the cave meteorology monitoring data collected within the Cumberland Piedmont Network (CPN). The monitoring questions and subsequent analysis of the supporting data address issues related to status and trends in air velocity in cave cross-sections. The status and trends of this parameter likely produce impacts on biotic and abiotic components of cave systems. Data collected through this protocol may be used to assess the impacts of management activities, such as cave entrance modification, upon cave air velocity. The sampling design provides periodic assessments of spatial distribution of air velocity in a cave cross-section as well as time series from a single, representative point in the cross-section. The periodic spatial data are analyzed to determine the optimal location for single-point sampling. These data may be collected over multi-year scales. When collected over long-term (as well as short-term) time scales, these data may be used to evaluate the impacts of management actions upon air velocity (and impacts on air velocity could have subsequent impacts on biotic and abiotic cave components). Monitoring questions will be addressed using a combination of summary and descriptive statistics, graphic analysis, and multivariate comparative and correlative analysis.

The protocol was designed to answer the following monitoring questions:

5. What is the status of air velocity within a given cave cross-section?
6. What is the trend over time in air velocity for these cave cross-sections?
7. How do management actions impact values in air velocity within a given cave cross-section?
8. What are the impacts of changes in a cross-section's air velocity upon air temperature and relative humidity in cave spaces that are near the cross-section?

Data Flow

The data manager will work with the project leader to ensure that data are regularly verified and rolled up into a master copy of the dataset in the "DBMS_Master" folder for this protocol (i.e.,

X\CUPN-MACA IM Projects...\CaveAirQuality\DBMS_Master). This folder is reserved for datasets that have already been validated, will no longer change, and with the exception of the data manager, is available to Cumberland Piedmont Network-MACA Prototype (CUPN-MACA) staff with read-only access privileges. This ensures that once data are validated, the dataset remains accessible to staff while being secure from accidental or undocumented changes. This copy of the dataset, which is in .mdb format, should be utilized by CUPN-MACA staff for all analyses.

The development of basic queries and summary reports in MS Access will be utilized to automate and thus streamline the data analysis and reporting workload, as appropriate. In consultation with the project leader, the data manager will develop queries (and accompanying summary reports) that will generate the following datasets:

- Air velocity time series as collected during periodic sampling.
- Air velocity time series as collected during monitoring mode.

These are basic datasets which the project leader anticipates using on an irregular, but frequent basis. It is anticipated the results of these queries will be relied upon heavily for annual reporting requirements to the parks, as well as internal reports generated for CUPN-MACA staff and cooperators. The data manager will construct these queries and reports within the front-end of the current version of the protocol's MS Access database stored in the X:\CUPN-MACA IM Projects . . . \CaveAirQuality\DBMS_Forms folder, which can be linked to the appropriate data tables on the MACA server. Note: This front-end database can be copied to the project leader's workstation in order to increase performance. However, the working and master back-end databases should remain on the MACA server in their respective folders at all times.

In instances where statistical analyses become increasingly complex, data will need to be exported out of the relational MS Access database to commercial off-the-shelf statistical packages. CUPN-MACA staff primarily utilize SigmaStat, Systat, and SigmaPlot for frequency distribution plots, test for normality, analysis of variance, time series analysis, etc. In these instances, the data manager will work with the project leader and other CUPN-MACA staff to format data for export. In general, these data will be formatted based on parameters provided to the data manager via a make-table query in MS Access. The generated table will be exported in comma delimited ASCII text format.

Data Analysis

Data in comma delimited ASCII text format are readily imported into statistical analysis software used at CUPN-MACA (e.g., SigmaStat and SigmaPlot). The sequence of steps for data import within SigmaStat and SigmaPlot are:

1. Launch SigmaStat or SigmaPlot.
2. Click on File to view the File menu.
3. Select Import from the File menu.
4. A window will open in which the user can select the appropriate file type and the file to be imported. There will be a drop-down list from which the appropriate file type may be

selected. Select “Plain Text.” Then, navigate to the appropriate folder and select the desired file.

5. Now, a new window is launched in which the field format must be indicated. Select “Delimiter” and the comma from the associated drop-down list. Click on “Import.”

We anticipate that analyses will explore the behavior of cave meteorological sample parameters over time. Data managers will provide make-table queries within the database to be used for data export. These data will be imported into SigmaStat or SigmaPlot for higher level statistical analyses (i.e. t-tests and ANOVA).

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 8: Reporting

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This SOP gives step-by-step instructions for reporting on cave meteorology parameters (air temperature, relative humidity, and air velocity) at parks throughout the Cumberland Piedmont Network. This SOP describes the procedure for formatting a report, the report review process, and distribution of completed reports. Efficient reporting on monitoring results is critical in assisting park resource managers with management decisions. Therefore, a reporting schedule is given with key reporting dates identified. Timely production of appropriate reports is the responsibility of the project leader and the MACA Program coordinator.

Report Format

General

Reports should be produced on high quality white paper, 215 x 280 mm in size. Font size of all text should be 12 point unless smaller font aids in fitting information on tables. Times New Roman font should be the standard font utilized. However, other text fonts are acceptable if used consistently throughout the document. Text is left justified with 3-cm margins on all sides. Words should not be hyphenated on the right side of text.

Page numbers and headers should be placed in the upper-right corner of each page starting with page two of the report. One exception to page numbering and headers is with figures (including pictures and illustrations), if a separate figure title page is used, place number and heading on these pages and leave them off pages containing the figures. Headers should contain an abbreviated version of the report title.

Bolding and underlining should be used minimally in the body of the text unless used on section headings and subheadings. Use italic font for scientific names of species. When using both common and scientific names, list scientific name with first mention of common name only.

Three levels of section headings may be used. First-level headings are all upper-case letters, bolded and left-justified with a sequenced whole number to its left. Second-level headings are

bolded and left justified similar to first-level headings with sequenced numbers to the first decimal place. However, only the first letter in each word is capitalized. Third-level headings are indented five spaces and the first letter in each word is capitalized. Third-level headings are not bolded, underlined or numbered. Third-level headings may be italicized followed by a period and two hyphens or bulleted.

Reports should be direct and concise, avoiding superfluous wording. Refer to CBE Style Manual (CBE Style Manual Committee 1994) or Writing with Precision, Clarity and Economy (Mack 1986) for aids in writing. Also see Strunk and White (1979), Day (1983), and “Notes on Writing Papers and Theses” (Lertzman 1995) for help in structuring sentences and paragraphs for clarity.

Tables

Tables should be placed within the text of a report or immediately following the literature cited section. Tables should be numbered in sequence regardless of where they are located. Table headers are placed at the top of a table. Horizontal lines are used to separate the table heading from column headings, column headings from the table and to signify the end of the table. Vertical gridlines lines should not appear on a table.

Figures

Figures should be placed within the text of a report or immediately following tables behind the literature cited sections. Figures should be numbered in sequence regardless of where they are located. Figure captions are placed below the figure if it is included in the text or on a separate sheet of paper preceding the figure if included after the literature cited section. Both tables and figures should contain information not presented in the body of the text. Also, tables and figures should not duplicate information already presented in the body of the text.

Pictures

Treat as figures.

Report Outline

TITLE PAGE

- Title
- Author(s)
- Institutions
- Prepared for
- Date

TABLE OF CONTENT PAGE (optional)

EXECUTIVE SUMMARY PAGE (abstract)

1.0 INTRODUCTION

1.1 Background

1.2 Justification for Study

1.3 Objectives

2.0 METHODS

2.1 Study area(s)

2.2 Field method(s)

2.3 Analytical method(s)

3.0 RESULTS

4.0 DISCUSSION

5.0 MANAGEMENT IMPLICATIONS

6.0 ACKNOWLEDGEMENTS

7.0 LITERATURE CITED

(See Section IV, Literature Cited for format examples)

APPENDICES (optional)

Review Procedure

Internal Review

Annual reports on cave meteorology monitoring will be written by the project leader, and/or crew leader(s) under the direction of the project leader. One or more internal reviews for grammatical soundness will be sought prior to submitting the report to MACA Management and Cumberland Piedmont Network (CUPN) Management. Internal review by MACA Prototype or CUPN personnel skilled in technical writing for clarity and directness should fulfill this review requirement. Internal reviews will be conducted by MACA Prototype staff and/or other persons sought out for their language skills.

If reports are written to update findings only and they do not deviate significantly from previously reviewed and distributed reports then the review process may stop here. However, review by park staff and subsequent external reviews must be sought for new reports or those that deviate significantly from previously reviewed and distributed reports. Also, if management activities within a park are not clearly understood, then park review should be sought for a report to clarify results and management implications.

Park Review

Park staff, generally Resource Managers, are in a unique position in that they can supply details about management activities that may influence findings presented in a report. Also, they will be the ones applying management recommendations to their park. Therefore, review by park staff is vital to the interpretation of findings and the assessment of proposed management

implications. Review by park staff should be conducted before a report is submitted for external review.

External Review

External review by two or more experts in air quality monitoring should be sought for the first report in a series of annual reports and trend reports. In addition, analytical methods employed on data presented in the report need to be reviewed by one or more statisticians. If a report updates a previously reviewed and distributed report then external review is not required. However, external reviews must be sought for new reports or those that deviate significantly from previously reviewed and distributed reports. In order to conserve reviewer time, external reviews must follow the internal and park review process.

All review comments must be addressed, be it their inclusion in the report or reason for excluding them from the report. The responsibility to edit a report falls to the senior author of the report or their designee.

Distribution Procedure

Identifying Stakeholders

The primary stakeholder in our cave meteorology monitoring efforts is the National Park Service management staff at MACA, the CUPN, and any of the national park units with cave/karst resources. Potential stakeholders include state and federal wildlife agencies, universities, and the general public. Although this particular monitoring project is not part of any national or regional effort, any natural resource specialist conducting (or considering conducting) cave meteorology monitoring should be interested in project results. Initial implementation of this protocol will be addressed at MACA and throughout the CUPN upon the protocol's completion.

Distributing Reports

Annual reports will be provided to resource managers at CUPN parks as appropriate. Additionally, a copy will be kept on file with the CUPN office of the National Park Service, Mammoth Cave, Kentucky and made available to all interested parties upon request.

All data collected by the MACA Prototype is of course, public property and is subject to requests under the Freedom of Information Act (FOIA). The data management plan for the CUPN-MACA Monitoring program (Moore et al. 2004) describes appropriate procedures to respond to FOIA requests, including the protection of sensitive data such as cave and endangered species locations. Reports containing non-sensitive data will be disseminated through the CUPN-MACA Monitoring program's website. Through the website, those requesting information will be asked to provide information to document by whom and for what purpose the report is being used. By documenting requests, users can be informed when updated reports are available. Users requesting paper copies will be documented also.

In an effort to disseminate findings in a timely manner, annual reports should be completed by March 31 of the year following data collection. A brief (2-3 paragraphs) summary of sampling activities, preliminary results, and any public interest highlights that occurred during each federal fiscal year will be written by October 15 for inclusion in the CUPN-MACA Monitoring

program's Annual Administrative Report. More extensive summary reports (long-term trend reports) should be completed every five years. These reports will be centered upon cave meteorology, but will also synthesize findings among several vital signs being monitored at MACA that display cross correlation. Summary reports may be used in place of annual reports for the year in which the last data is collected.

Literature Cited

Moore, W. J., R. Byrd, and T. R. Leibfreid. 2005. Data management plan for the Cumberland Piedmont Network and Mammoth Cave National Park Prototype Monitoring Program. USDI National Park Service. Mammoth Cave, KY. 81pp.

CBE Style Manual Committee. 1994. Scientific style and format: the CBE manual for authors, editors, and publishers. Sixth edition. Council of Biology Editors, Cambridge University Press, New York, New York, USA.

Day, R. A. 1983. How to write and publish a scientific paper. Second edition. ISI Press, Philadelphia, Pennsylvania, USA.

Lertzman, K. 1995. Notes on writing papers and theses. Bulletin of the Ecological Society of America **76**:86-90.

Mack, R. N. 1986. Writing with precision, clarity, and economy. Bulletin of the Ecological Society of America **67**:31-35.

Strunk, W. Jr., and E. B. White. 1979. The elements of style. Third edition. Macmillan, New York, New York, USA.

A Protocol for Monitoring Cave Meteorology throughout the Cumberland Piedmont Network

Standard Operating Procedure (SOP) # 9: Revising the Protocol

Version 1.0 (March 2007)

Revision History Log:

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This Standard Operating Procedure explains how to make changes to the cave meteorology monitoring Protocol Narrative for Cumberland Piedmont Network (CUPN) and accompanying SOPs, and how to track these changes. Any changes in the cave meteorology monitoring protocol will adhere to the guidelines contained in this SOP. Observers asked to edit the Protocol Narrative or any one of the SOPs need to follow this outlined procedure in order to eliminate confusion in how data are collected and analyzed. All observers should be familiar with this SOP in order to identify and use the most current methodologies, and should see the revision history log attached to each SOP.

Procedures

1. The cave meteorology monitoring protocol for CUPN and (Narrative and accompanying SOPs) has attempted to incorporate the most sound methodologies for collecting and analyzing data. However, all protocols regardless of how sound require editing as new and different information becomes available. Required edits should be made in a timely manner and appropriate reviews undertaken.
2. All edits require review for clarity and technical soundness. Oversight of the revision process for all protocols is the responsibility of the MACA Prototype coordinator. When a potential modification to a protocol is identified, the project leader consults with the prototype coordinator, who then decides whether the change should be considered “small” or “significant”. Small changes or additions to existing methods will be reviewed in-house by MACA Prototype staff designated by the prototype coordinator. However, if a substantial change, such as a change in methods is sought, then an outside review may be required. The need will be determined by the protocol coordinator and project leader. Reviewers will be selected based on the type of change (i.e., changes in sampling sites versus changes in sampling design or sampling analysis). Regional and National staff of the National Park Service, as well as the U.S. Geological Survey-Biological Resource Discipline, with familiarity in ecological research and data analysis will be utilized as reviewers. Also,

experts in air quality monitoring, research, and statistical methodologies outside of the National Park Service will be utilized in the review process, as needed.

3. Document all edits and protocol versioning in the Revision History Log that accompanies the Protocol Narrative and each SOP. Log changes in the Protocol Narrative or SOP being edited only. Version numbers increase incrementally by hundredths (e.g. version 1.01, version 1.02, ...etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 ...etc). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number.
4. Depending upon the magnitude and nature of a proposed change, it could have significant implications for data management. The database may have to be edited by the data manager to accompany changes in the Protocol Narrative and SOPs. The database may have to be edited by the data manager to accompany changes in the Protocol Narrative and SOPs. Thus the data manager must be consulted prior to implementing changes to protocols. Immediately after the changes to the Protocol Narrative or SOP(s) have been made, inform the data manager, so the new version number can be incorporated in the metadata of the project database.

Post new versions on the Internet and in the “Narratives” or “SOP” subfolder for the project. Forward copies to all individuals with a previous version of the effected Protocol Narrative or SOP. Archive a copy of each previous version in the MACA curatorial facility.

Appendix A - Air Temperature/Relative Humidity Seasonal Sampling – Field Operations Notes

Equipment List

1. Spiral rite-in-the-rain notebook for plot collateral data
2. Pelican case or compartmentalized backpack which contains:
 - a. Programmed Campbell Scientific Inc. datalogger
 - b. Charged 12-volt battery
 - c. Power cable for connecting Campbell datalogger to 12-volt battery
 - d. Vaisala air temperature / relative humidity probe (attached via manufacturer supplied signal wire)
3. ~2m PVC pipe (1/2" schedule 40 is recommended) for attachment to at/rh probe
4. Rangefinder with fresh batteries
5. Compass
6. Tripod with laser-mount
7. Two (2) lasers, each with fresh batteries
8. Male-to-double female 9-pin serial cable
9. Six foot male-to-female 9-pin serial cable
10. Campbell Scientific keypad interface
11. Campbell Scientific's SM4M storage module
12. Electrical tape
13. Pencils or pens
14. Extra 9-volt and AA charged batteries
15. Necessary PPE.

Crew Leader Roles and Responsibilities

The crew leader is solely responsible for all aspects of a data collection event including: equipment preparation, data collection, and equipment storage / clean-up following the data collection event. The crew leader may opt to have some of these tasks completed by a designee. However, the crew leader should verify completion of assigned tasks before leaving the office.

Equipment preparation

1. Have you assembled necessary equipment from the equipment list above?
2. Is the datalogger's battery fully charged?
3. Are batteries for the lasers viable?
4. Is the probe's wiring securely attached to the datalogger's wiring panel?
5. Is the datalogger working properly?
6. Does the datalogger contain the proper program?
7. Is the datalogger date and time correct?
8. Have I completed a cave entrance form and had all expedition members sign the form?

Data collection

1. At a site outside the cave of interest and free of the cave's influence on air temperature / relative humidity, collect surface air temperature / relative humidity data. Did you:
 - a. Power the datalogger up by connecting the battery to the datalogger?
 - b. Connect the keypad to the datalogger via either 9-pin serial cable?
 - c. Key in *63A on the keypad?
 - d. Remove protective cap from the Vaisala at/rh probe?
 - e. Wait several minutes to allow the air temperature measured by the datalogger to stabilize?
 - f. Write down for pre-sample air temperature the value shown on the display?
 - g. Key in A on the keypad?
 - h. Write down for pre-sample relative humidity the value shown on the display?
 - i. Disconnect keypad / serial cable from the datalogger?
 - j. Power down datalogger by disconnecting battery?
2. Move to desired data collection location.
3. Set up siting equipment and datalogger at location's landmark. Did you:
 - a. Power up the datalogger by connecting the battery to the datalogger?
 - b. Set the tripod in the appropriate location?
 - c. Level the tripod?
 - d. Attach the surveying assembly to the tripod?
 - e. Remove the protective cap from the Vaisala at/rh probe?
 - f. Unroll the probe's cabling?
 - g. Attach the ~2m PVC pipe to the Vaisala assembly?
 - h. Attach the rangefinder target to the Vaisala assembly?
 - i. Attach the keypad to the datalogger using a 9-pin serial cable?
 - j. Key in *66A to verify that the current plot ID is zero?
 - k. Key in D to view the datalogger's eight flags?
 - l. Before proceeding to collect plot data, allow the datalogger to be on for several minutes to allow at/rh measurements to stabilize?
 - m. Set one (axial) laser on the floor to project an axial reference line?
 - n. Set a second (transect) laser on the floor orthogonal to the axial laser and at the first transect?
 - o. Send the probe assembly technician to the first sampling plot?
4. Collect plot data. Did you:
 - a. Verify that the probe assembly technician is in position?
 - b. Key in 1 on the keypad to activate the datalogger's first flag?
 - c. Observe the existence/absence of biota at the plot?
 - d. Make any relevant plot notes?
 - e. Once the value of the first flag has returned to zero, tell the probe assembly technician to move to the next plot?

- f. After a transect has been completed, move the transect laser to the next transect?
 - g. Repeat steps (4a) through (4f) until all transect plots are completed?
 - h. Allow the probe assembly technician to collect data in relevant, non-transect plots?
 - i. Periodically verify that the plot number in the datalogger (*66A) and the plot number on the Collateral Plot Data form coincide?
5. Offload datalogger data and equipment disassembly. Did you:
- a. Using the male-to-double female 9-pin serial cable, connect the keypad and storage module to the datalogger?
 - b. Key in *871AAA3A to offload the data?
 - c. Allow ample time for the offload to be completed?
 - d. Key in *0 on the keypad?
 - e. Disconnect and stow the serial cable, keypad, and storage module?
 - f. Power down the datalogger by disconnecting the battery?
 - g. Disassemble and stow all hardware for transport to the next sampling location or office?
6. Repeat steps (1) through (5) for subsequent sampling locations within the cave of interest.

Equipment Storage/Clean-up

1. Upload data from storage module to PC. Did you:
 - a. Using a male-to-female 9-pin serial cable, attach the storage module to your PC?
 - b. Launch Loggernet?
 - c. Select the Storage Module button within Loggernet?
 - d. Select the SM4M/SM16M tab within the storage module window?
 - e. Click on the Connect button?
 - f. Edit the file name and directory for the files about to be uploaded?
 - g. Click on the Get New button?
 - h. Once upload is complete, click on the Disconnect button?
 - i. Disconnect and stow storage module?
 - j. Close Loggernet?
2. Remove and stow batteries from all battery-powered equipment?
3. If necessary, place the Campbell datalogger's battery on charge?
4. Clean and repair all hardware as needed?
5. Stow hardware in the appropriate location(s)?

Campbell Scientific Datalogger Modes and Commands

Modes

The following keystrokes place you in the indicated mode:

- *0 – Return to the home screen (display is “Log 1” or “Log 12”).
- *5 – Time and date information. Key “A” and “B” to move through the date and time information, in the following order:

- Time
- Year
- Julian day
- Time set screen

- *6A – Intermediate memory for temporary data storage; shows data from the most recent program execution. Memory locations for the at/rh program house the following information:
 - 01 – Cave identification code
 - 02 – Landmark identification code
 - 03 – Vaisala air temperature
 - 04 – Vaisala relative humidity
 - 05 – Event timer
 - 06 – Plot identification number
 - 07 – Current Flag 1 value

Flags

- When in *6 mode, keying “D” allows you to view current flag values. Alternatively, keying “*6AD” in any mode takes you directly to the flag viewing screen.
- Toggle flags on and off by keying the digit on the keypad that corresponds to the flag number (i.e. for Flag 1, key “1,” for Flag 2, key “2,” etc.).

Alpha Keys

The four lettered keys on the keypad perform the following functions:

- “A” – Serves as the “Enter” key or ascends through date/time information and memory locations.
- “B” – Descends through date/time information and memory locations.
- “C” – Not used in this protocol.
- “D” – Accesses the flag screen when in *6 mode.

Julian Calendar

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

Note: Add 1 to unshaded values during leap years.

Appendix B - Air Temperature and Relative Humidity – Event Data

Cave _____ Date (mm/dd/yyyy) _____
 Landmark _____ Julian Day _____
 Surface Type (wall, floor, ceiling) _____
 Biota Type (crickets, beetles, bats, or none) _____

Pre-Sample Time (LST) _____ Post-Sample Time (LST) _____
 Pre-Sample Air Temperature (C) _____ Post-Sample Air Temperature (C) _____
 Pre-Sample Relative Humidity (%) _____ Post-Sample Relative Humidity (%) _____

Crew Leader _____ Crew Member _____

Event Notes

Office Use Only: File Name _____

Air Temperature and Relative Humidity – Collateral Plot Data: Biota Existence

<i>Plot</i>	<i>Biota Score</i>	Plot Notes	<i>Plot</i>	<i>Biota Score</i>	Plot Notes	<i>Plot</i>	<i>Biota Score</i>	Plot Notes
1			26			51		
2			27			52		
3			28			53		
4			29			54		
5			30			55		
6			31			56		
7			32			57		
8			33			58		
9			34			59		
10			35			60		
11			36			61		
12			37			62		
13			38			63		
14			39			64		
15			40			65		
16			41			66		
17			42			67		
18			43			68		
19			44			69		
20			45			70		
21			46			71		
22			47			72		
23			48			73		
24			49			74		
25			50			75		

Biota Score: 0 $\cong$ None, otherwise score using scale defined by program coordinator.

Appendix C - HOBO Pro RH/Temp Datalogger – Site Setup and Maintenance Field Observer Form

General Information

Cave Name _____ Cave ID _____
Landmark Name _____ Landmark ID _____
HOBO Serial Number _____
Crew Member _____
Date ____ ____ Time (LST) ____
mm dd yy

Datalogger installation status (check one):

____ Installed datalogger today. There was no datalogger at this location before today. Siting information:
Azimuth _____
Elevation _____
Distance _____

____ Servicing existing datalogger.

____ This datalogger is being replaced today. Serial number of:

Datalogger being replaced _____

Datalogger being installed _____

Servicing notes (for existing dataloggers):

Datalogger undisturbed? Y N

Changed battery? Y N

If Y:

Cleaned o-ring? Y N

Greased o-ring? Y N

Cleaned o-ring groove? Y N

Replaced dessicant? Y N

Data transfer successful? Y N

Datalogger relaunched? Y N

Notes: _____

General Information

Cave Name _____ Cave ID _____
Landmark Name _____ Landmark ID _____
HOBO Serial Number _____
Crew Member _____
Date ____ ____ Time (LST) ____
mm dd yy

Datalogger installation status (check one):

____ Installed datalogger today. There was no datalogger at this location before today. Siting information:
Azimuth _____
Elevation _____
Distance _____

____ Servicing existing datalogger.

____ This datalogger is being replaced today. Serial number of:

Datalogger being replaced _____

Datalogger being installed _____

Servicing notes (for existing dataloggers):

Datalogger undisturbed? Y N

Changed battery? Y N

If Y:

Cleaned o-ring? Y N

Greased o-ring? Y N

Cleaned o-ring groove? Y N

Replaced dessicant? Y N

Data transfer successful? Y N

Datalogger relaunched? Y N

Notes: _____

Appendix D - Cross-Sectional Airflow - Field Operations Notes

Equipment List – Initial Site Setup

1. Digital camera
2. Pelican case(s), each of which contains:
 - a. Programmed Campbell Scientific Inc. datalogger
 - b. Charged 12-volt battery
 - c. Power cable for connecting Campbell datalogger to 12-volt battery
 - d. Phone terminal that is wired into the Campbell datalogger
 - e. Gill Instruments WindSonic two dimensional sonic anemometers and their vertical mounts as needed
3. Tripods as needed
4. Hoseclamps as needed
5. Mapping equipment
6. Male-to-double female 9-pin serial cable
7. Campbell Scientific keypad interface
8. Campbell Scientific's SM4M storage module
9. Electrical tape
10. Plumber's putty
11. Pencils or pens
12. Necessary PPE.

Additional supplies are necessary to make the equipment field-ready. These supplies are as follows.

1. Campbell Scientific's Loggernet software
2. SC32A interface (for communication between the Campbell datalogger and Loggernet)
3. One 25-pin to 9-pin serial cable
4. One 9-pin serial cable
5. Owner's manuals for hardware being used

Roles and Responsibilities

The crew leader is solely responsible for all aspects of a data collection event including: equipment preparation, data collection, and equipment storage / clean-up following the data collection event. A suggested event execution schedule follows.

Seasonal Sampling – In-office Preparations

1. As necessary, assign an SDI -12 address to each Gill Instruments Windsonic anemometer. The default SDI-12 address for a new anemometer is 0. For this protocol, one anemometer should have as its SDI-12 address 0, and the remaining anemometers should have addresses 1,2,3,4, and 5. Instructions for changing an

SDI-12 address may be found in SOP 2. Using the attached labels, label each anemometer head with its SDI-12 address.

2. Attach anemometers to datalogger to verify proper program is being utilized.
 - a. If not yet completed, connect each of the anemometer's signal/power wires to the proper wires on an RJ11 phone jack adapter.
 - b. Connect the phone line junction box to the datalogger.
 - c. Connect all anemometers to the phone line junction box.
 - d. Power up the datalogger.
 - e. Connect datalogger to a PC with Loggernet installed.
 - f. Use Loggernet to view data as they are being collected by the datalogger. Verify that values seen are reasonable and no error codes are shown.
 - g. Disconnect datalogger from PC.
 - h. Power down datalogger.
 - i. Disconnect anemometers from phone line connection box.
 - j. Repeat steps if necessary for an additional datalogger.
3. Assemble all necessary equipment for transport to the field.
 - a. Have you assembled necessary equipment from the equipment list above?
 - b. Is the datalogger's battery fully charged?
 - c. Is the probe's wiring securely attached to the datalogger's wiring panel?
 - d. Is the datalogger working properly?
 - e. Does the datalogger contain the proper program?
 - f. Is the datalogger date and time correct?
 - g. Has a cave entrance form been completed and have all expedition members signed the form?
 - h. Have you left the phone line junction box connected to the datalogger? Have you attached the vertical mounts to all anemometer heads? Cabling should have been run through the vertical mount.

Seasonal Sampling – Site Setup

1. Move to desired data collection location.
2. Assemble and install tripods.
3. Attach anemometer heads to tripods, running cables as necessary.
4. If the cross-section of interest has not been mapped, map the cross-section's size and shape. Did you:
 - a. This section of instructions will be completed at a later time, when the hardware necessary for mapping a cross-section has been constructed.
5. Map the locations of the anemometer heads. Did you:
 - a. This section of instructions will be completed at a later time, when the hardware necessary for mapping of anemometer head locations has been constructed.

6. Connect anemometer cabling to the datalogger, being certain to weatherproof the cabling's opening through the Pelican case.
7. Place fresh dessicant in a container in the Pelican case.
8. Power up datalogger.
9. Connect the keypad to the datalogger using a 9-pin serial connector-cable.
10. Verify datalogger date and time is correct (*5 mode).
11. Verify that anemometer data are reasonable (*6 mode). Write the observed values onto the field form.
12. Return the datalogger to the "Log" screen by keying *0.
13. Disconnect the keypad.
14. Stow the keypad and its 9-pin serial connector-cable.
15. Close the Pelican case to weatherproof the datalogger.
16. If the current anemometer arrangement has not been photographed at this site, take site photographs.
17. Complete the Site Setup Form.

Seasonal and Monitoring Mode – Site Maintenance

1. Verify that anemometers are unobstructed and tripods/cabling are secure.
2. Open Pelican case.
3. Connect keypad and storage module to datalogger using male-to-double female 9-pin serial cable.
4. Verify that datalogger date and time is correct (*5 mode).
5. Verify that anemometer data are reasonable (*6 mode).
6. Offload data by keying *871AAA3A (for CR10X dataloggers).
7. Change dessicant while offload is completing.
8. Allow ample time for the offload to be completed.
9. Key in *0 on the keypad.
10. Change datalogger battery. Note: battery exchange should be performed using a wiring pig (a wiring harness that allows simultaneous connection of two batteries so that the datalogger is never without power). Instructions for construction of this pig are included in this protocol.
 - a. With the depleted battery in place, connect the charged battery to the unused pair of leads.
 - b. Disconnect the depleted battery.
11. Verify that the new battery voltage is approximately between 13.0 and 13.1 volts.
12. Key in *0.
13. Disconnect and stow the serial cable, keypad, and storage module.
14. Close Pelican case.
15. Verify that site is still secure (no cabling has been kicked out of place, etc).
16. Complete the field observer form.
17. Service additional sites and/or return to office.

18. Upload data from storage module to PC as outlined in the following section: *Seasonal Sampling and Monitoring Mode – Datalogger Offloads and Data Transfer to a PC.*

Seasonal Sampling and Monitoring Mode – Datalogger Offloads and Data Transfer to a PC

1. Offload data from datalogger. Did you:
 - a. Using the male-to-double female 9-pin serial cable, connect the keypad and storage module to the datalogger?
 - b. Key in *871AAA3A (for CR10X dataloggers) to offload the data?
 - c. Allow ample time for the offload to be completed?
 - d. Key in *0 on the keypad?
 - e. Disconnect and stow the serial cable, keypad, and storage module?
2. Upload data from storage module to PC. Did you:
 - a. Using a male-to-female 9-pin serial cable, attach the storage module to your PC?
 - b. Launch Loggernet?
 - c. Select the Storage Module button within Loggernet?
 - d. Select the SM4M/SM16M tab within the storage module window?
 - e. Click on the Connect button?
 - f. Edit the file name and directory for the files about to be uploaded?
 - g. Click on the Get New button?
 - h. Once upload is complete, click on the Disconnect button?
 - i. Close Loggernet?

Equipment Storage/Clean-up

Did you:

1. Remove and stow batteries from all battery-powered equipment?
2. Place the Campbell datalogger's battery on charge?
3. Clean and repair all hardware as needed?
4. Stow hardware in the appropriate location(s)?

Campbell Scientific Datalogger Modes and Commands

Modes

The following keystrokes place you in the indicated mode:

- *0 – Return to the home screen (display is “Log 1” or “Log 12”).
- *5 – Time and date information. Key “A” and “B” to move through the date and time information, in the following order:
 - Time
 - Year
 - Julian day
 - Time reset screen
- *6A – Intermediate memory for temporary data storage; shows data from most recent program execution. Memory locations house the following information:

Datalogger 1

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 0 diagnostic
- 06 – Anemometer 0 wind speed
- 07 – Anemometer 0 wind direction
- 08 – Anemometer 0 sample count
- 09 – Anemometer 1 diagnostic
- 10 – Anemometer 1 wind speed
- 11 – Anemometer 1 wind direction
- 12 – Anemometer 1 sample count
- 13 – Anemometer 2 diagnostic
- 14 – Anemometer 2 wind speed
- 15 – Anemometer 2 wind direction
- 16 – Anemometer 2 sample count

Datalogger 2

- 01 – Cave identification code
- 02 – Cross-section identification code
- 03 – Monitoring status
- 04 – Battery voltage
- 05 – Anemometer 3 diagnostic
- 06 – Anemometer 3 wind speed
- 07 – Anemometer 3 wind direction
- 08 – Anemometer 3 sample count
- 09 – Anemometer 4 diagnostic
- 10 – Anemometer 4 wind speed
- 11 – Anemometer 4 wind direction
- 12 – Anemometer 4 sample count
- 13 – Anemometer 5 diagnostic
- 14 – Anemometer 5 wind speed
- 15 – Anemometer 5 wind direction
- 16 – Anemometer 5 sample count

Flags

- When in *6 mode, keying “D” allows you to view current flag values. Alternatively, keying “*6AD” in any mode takes you directly to the flag viewing screen.
- Toggle flags on and off by keying the digit on the keypad that corresponds to the flag number (i.e. for Flag 1, key “1,” for Flag 2, key “2,” etc.).

Alpha Keys

The four lettered keys on the keypad perform the following functions:

- “A” – Serves as the “Enter” key or ascends through date/time information and memory locations.
- “B” – Descends through date/time information and memory locations.

- “C” – Not used in this protocol.
- “D” – Accesses the flag screen when in *6 mode.

Julian Calendar

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

Note: Add 1 to unshaded values during leap years.

Anemometer Labels

SDI-12 Address = 0

SDI-12 Address = 1

SDI-12 Address = 2

SDI-12 Address = 3

SDI-12 Address = 4

SDI-12 Address = 5

Datalogger Labels

CUPN – Cave Airflow Monitoring
Datalogger 1
SDI-12 Addresses = 0,1,2

CUPN – Cave Airflow Monitoring
Datalogger 2
SDI-12 Addresses = 3,4,5

Appendix E – Cave Cross-sectional Airflow – Site Maintenance Field Observer Form

General Information

Cave Name _____ Cave ID _____
 Cross-Section Name _____ Cross-Section ID _____
 Monitoring Status (circle one): monitoring seasonal sampling
 Operator _____ Date ____ mm ____ dd ____ yy

Datalogger 1 Data – Anemometers 0, 1, and/or 2

Time (LST) (*5) ____ Year (A) ____ Julian Day (LST) (A) ____

MemLoc:Field Description (Keystroke) Observed Data

01: Cave ID (*6) _____
 02: Cross-section ID (A) _____
 03: Monitoring Status (A) _____
 04: Battery Voltage (A) _____
 05: Anemometer 0 Wind Direction (A) _____
 06: Anemometer 0 Wind Speed (A) _____
 07: Anemometer 0 Diagnostic (A) _____
 08: Anemometer 0 Sample Count (A) _____
 09: Anemometer 1 Wind Direction (A) _____
 10: Anemometer 1 Wind Speed (A) _____
 11: Anemometer 1 Diagnostic (A) _____
 12: Anemometer 1 Sample Count (A) _____
 13: Anemometer 2 Wind Direction (A) _____
 14: Anemometer 2 Wind Speed (A) _____
 15: Anemometer 2 Diagnostic (A) _____
 16: Anemometer 2 Sample Count (A) _____

Are data reasonable? Y N

Datalogger 1 Maintenance

Instrument supports and cabling secure? Y N
 Downloaded Data (*871AAA3A)? Y N
 Changed Desiccant? Y N
 Changed Battery? Y N If yes, new voltage (*613A) _____

Datalogger 1 Notes: _____

Datalogger 2 Data – Anemometers 3, 4, and/or 5

Time (LST) (*5) ____ Year (A) ____ Julian Day (LST) (A) ____

MemLoc:Field Description (Keystroke) Observed Data

01: Cave ID (*6) _____
 02: Cross-section ID (A) _____
 03: Monitoring Status (A) _____
 04: Battery Voltage (A) _____
 05: Anemometer 3 Wind Direction (A) _____
 06: Anemometer 3 Wind Speed (A) _____
 07: Anemometer 3 Diagnostic (A) _____
 08: Anemometer 3 Sample Count (A) _____
 09: Anemometer 4 Wind Direction (A) _____
 10: Anemometer 4 Wind Speed (A) _____
 11: Anemometer 4 Diagnostic (A) _____
 12: Anemometer 4 Sample Count (A) _____
 13: Anemometer 5 Wind Direction (A) _____
 14: Anemometer 5 Wind Speed (A) _____
 15: Anemometer 5 Diagnostic (A) _____
 16: Anemometer 5 Sample Count (A) _____

Are data reasonable? Y N

Datalogger 2 Maintenance

Instrument supports and cabling secure? Y N
 Downloaded Data (*871AAA3A)? Y N
 Changed Desiccant? Y N
 Changed Battery? Y N If yes, new voltage (*613A) _____

Datalogger 2 Notes: _____

Appendix F - Cave Cross-sectional Airflow – Seasonal Equipment Setup or Disassembly Field Observer Form

General Information

Cave Name _____
 Cross-Section Name _____
 Landmark Name _____
 Distance from Landmark (m) _____
 Operator _____
 Activity (circle one): Equipment Setup Equipment Disassembly
 Mapped Cross-Section Today? Y N
 Date ____ ____ ____
 mm dd yy

Office Use Only
 Cave ID _____
 Landmark ID _____
 Cross-Section ID _____
Obtain values before going into the field!

SDI-12 Address	Anemometer Head Mapping Angle (degrees)	Distance (m)
0	_____	_____
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____

Mapping Notes

Datalogger 1 Data – Anemometers 0,1, and/or 2

Time (LST) (*5) ____ Year (A) ____ Julian Day (LST) (A) ____

MemLoc:Field Description (Keystroke) Observed Data

01: Cave ID (*6) _____ To edit: *11AAxxxxA, *0
 02: Cross-section ID (A) _____ To edit: *12AAxxxxA, *0
 03: Monitoring Status (A) _____ To edit: *13AAxxxxA, *0
 04: Battery Voltage (A) _____
 05: Anemometer 0 Wind Direction (A) _____
 06: Anemometer 0 Wind Speed (A) _____

07: Anemometer 0 Diagnostic (A) _____
 08: Anemometer 0 Sample Count (A) _____
 09: Anemometer 1 Wind Direction (A) _____
 10: Anemometer 1 Wind Speed (A) _____
 11: Anemometer 1 Diagnostic (A) _____
 12: Anemometer 1 Sample Count (A) _____
 13: Anemometer 2 Wind Direction (A) _____
 14: Anemometer 2 Wind Speed (A) _____
 15: Anemometer 2 Diagnostic (A) _____
 16: Anemometer 2 Sample Count (A) _____

Are data reasonable? Y N

Datalogger 2 Data – Anemometers 3,4, and/or 5

Time (LST) (*5) ____ Year (A) ____ Julian Day (LST) (A) ____

MemLoc:Field Description (Keystroke) Observed Data

01: Cave ID (*6) _____ To edit: *11AAxxxxA, *0
 02: Cross-section ID (A) _____ To edit: *12AAxxxxA, *0
 03: Monitoring Status (A) _____ To edit: *13AAxxxxA, *0
 04: Battery Voltage (A) _____
 05: Anemometer 3 Wind Direction (A) _____
 06: Anemometer 3 Wind Speed (A) _____
 07: Anemometer 3 Diagnostic (A) _____
 08: Anemometer 3 Sample Count (A) _____
 09: Anemometer 4 Wind Direction (A) _____
 10: Anemometer 4 Wind Speed (A) _____
 11: Anemometer 4 Diagnostic (A) _____
 12: Anemometer 4 Sample Count (A) _____
 13: Anemometer 5 Wind Direction (A) _____
 14: Anemometer 5 Wind Speed (A) _____
 15: Anemometer 5 Diagnostic (A) _____
 16: Anemometer 5 Sample Count (A) _____

Are data reasonable? Y N

Datalogger Notes

Appendix G – NPS/WKU Engineering Instrumentation Lift Project System Installation and Operation Procedures

Written by Western Kentucky University Engineering Faculty and Staff

Lift Project Overview

The scope of the instrumentation lift project was to construct two movable instrument mounting systems, each supports a variety of instruments and a data logging system onto two platforms, one located at the top of the tower at an elevation of up to 10 meters, the second platform would be capable of moving up and down between the top platform and approximately one foot from the ground. The combined weight of instrumentation and recording devices for both platforms is expected to be approximately 10 pounds.

WKU Engineering has completed the system design, fabrication and testing and our systems meet the following specifications:

- Each tower has ten 3-foot sections of screwed carbon reinforced PVC piping
- A four-legged based frame system supports the tower, assists in the raising and lower of the tower, and is a part of the stabilization of the tower
- A dual tensioning system connects the top of the tower and mid-point of the tower to the based frame
- A motor driven system allows for the raising and lowering of the movable platform and equipment
- A control system allows the user to program the movable tower to move and stop at selected heights, and to operate independently for extended periods of time

WKU Engineering believes that the completed the systems also meet the following design attributes:

- Will not damage any surfaces of the cave
- Reasonably lightweight and durable – shock-resistant, moisture-proof, easy to dry out and clean, non-corroding body and parts
- Modular to allow acceptable transport by two NPS personnel
- Easy to set up and move – (by 2 people for an 18' tower or less, 3 people for a tower greater than 18')
- Can support multiple instruments, weighing as much as 10 pounds
- Can be modified to support instruments along its height
- Can be repaired in-house

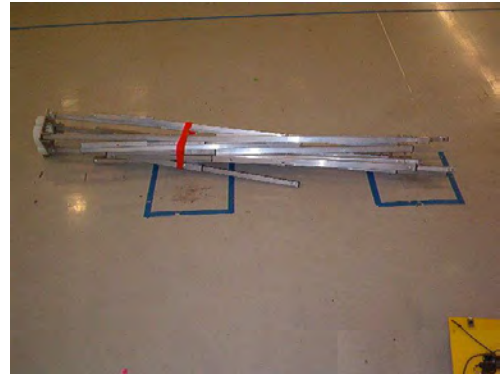
Tower Installation Procedures

The sequence of installation instructions below should be carefully read before starting the installation of a tower, and then used for guidance by NPS personnel to assist in the installation of a tower.

Caution: Only NPS personnel who have some experience in building shorter towers should build towers above 18 feet.

Building the tower base support:

The tower base should be stored from previous use with the four main legs retracted and pinned in a retracted position. (They will be pinned in hole #1 for storage.) Remove any bands securing the tower legs together and extend and re-pin the four legs in hole #3.

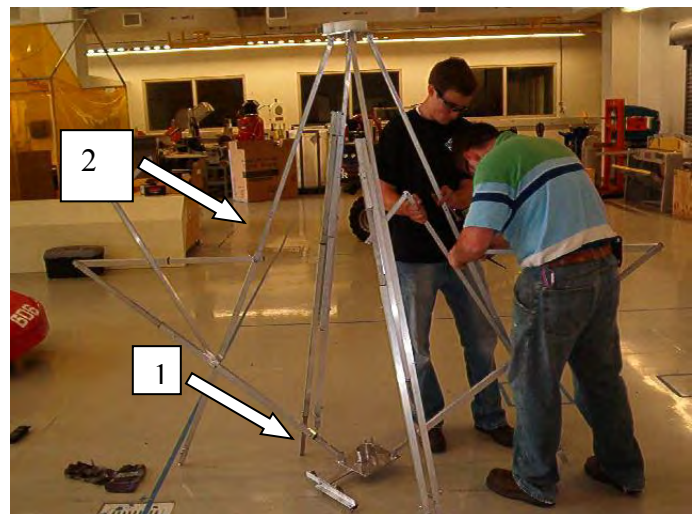


Arrange the tower base legs into the intended location, with the four legs evenly spread out.

Use caution, the base is not stable at this point.



Pivot the four outrigger sections so that the:
(1) lower portion of each outrigger is near the ground in the center of the tower, and the
(2) shorter horizontal portion is near the main tower legs.



Pin the horizontal end of the outrigger to the tower at hole #3.



Loosely connect the lower end to the bottom PVC holding plate (final tightening will take place later).
Make sure to position the movable tower cable system on the side where the moving platform will go.



Connect the four outriggers into hole #2.



Pin the frame that supports the center plate to each of the main legs



Repeat for all four components.

Now take care to tighten all bolts on the tower that have been installed so far. (3 bolts on each leg)



Take the center plate, open it flat and lock it into the flat position and secure and tighten to the tower base. **Make sure to position the slot for the moving platform on the desired side of tower.**



Place the four tensioner spool devices onto the ends of each outrigger component. These pieces slide into place and are secured when the tensioner cables are connected to the tower.



Keep the tensioner cord neatly wrapped around the spools while PVC tower is being raised. **Look out for the tensioner cords to get snagged during tower raising.**



Raising the tower:

The top instrument platform, with all instruments and cabling, should be screwed into the top PVC pipe section. The cord for the movable platform should be stored in the upper pulley system; **all of the cord needs to be available when the tower raising begins.**



Be sure to locate the clipped end of the cord at the top platform side with the moving platform support.



Then put the platform through the top of the support base.



The tower should look as shown to the right. The top platform pulley system should be clipped to the moving platform (lying on the ground near the tower) on one side of the platform, and connected to the motor (also lying near the tower). The motor will be mounted and the cord spooled later.



The four tensioner cables that connect to the top platform can now be connected. Use the tensioner cords from the larger spools – the smaller spools attach to the PVC at mid tower.



When completed the tensioner cables will look as shown to the right. Arrange the cords around the spools to avoid tangling or catching



Attach the two moving platform guide cables to the top platform. Leave sufficient cable – the moving platform cable connections will be made at the tower base when the tower is completely raised.



The PVC tower can now be raised. Before starting this step, determine the intended height. Using the table below you will determine the location of the mid-tower tensioner (PVC pipe with loops to hold tensioners)

Total # of Tower Sections	Location of Mid-Tensioner from Top
3 or 4	none required
5	2 from top
6*	2 from top
7*	3 from top
8*	3 from top
9*	3 from top
10*	4 from top

* Above a 15 ft. (5 section) tower, 3 people are required to install

Prior to raising the piping, level the base at the four legs, using the pinned leg extensions first, and then make fine adjustment using the screws at the bottom.

One person should hold the top pipe, while the second person screws in a lower pipe section. It is not necessary to screw the pipe more than modestly tight. If necessary the pipe clamp can be used to hold the pipe, however this does not seem necessary. When completed the partially completed tower can be rested on the lower base plate.



Continue to raise the tower. It is necessary to be careful about the tensioner cords catching on the platform during this process – particularly as the tower gets taller.



Insert the PVC pipe with the clamps for the mid-level tensioner at the proper position, and then install the four tensioner cables as shown.



When the tower has been raised to the desired height, the base of the PVC should be inserted into the lower base shoe, and the clamp at the top of the support frame should be clamped shut.



The tensioners should be tightened to secure and align the tower. This should be done carefully and evenly. Partially tighten each pair of cables, then repeat for the opposite side until all four pairs are slightly taut, then gradually align the tower and tighten all of the cords.



Suggestion: use fingers (right picture) tighten both cords equally before inserting into tensioner and locking in place by rotating tensioner.

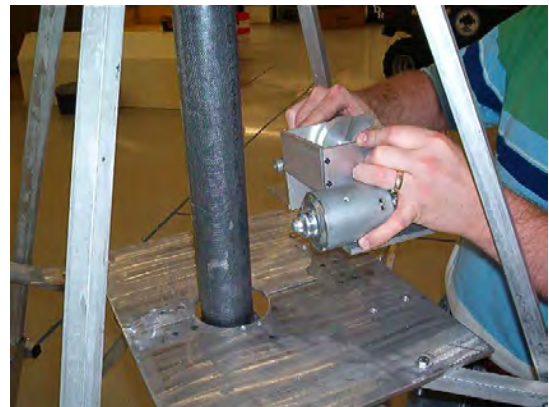
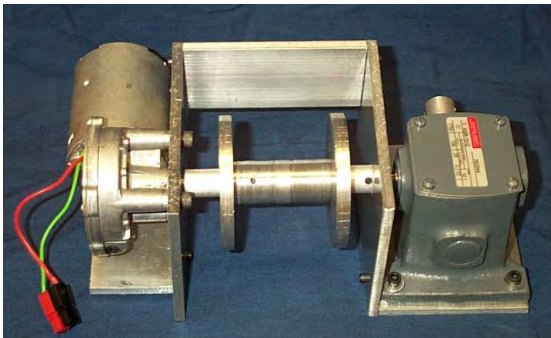


The tower should now look as shown to the right.

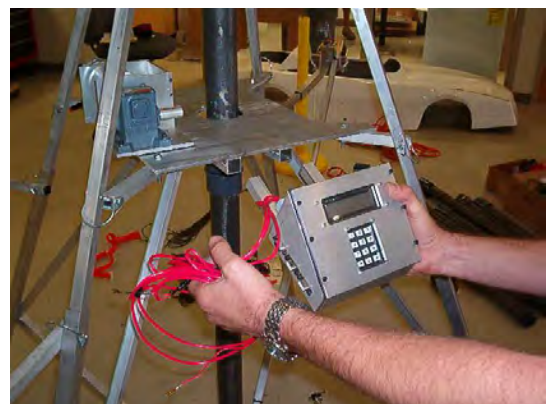


Installing the motor:

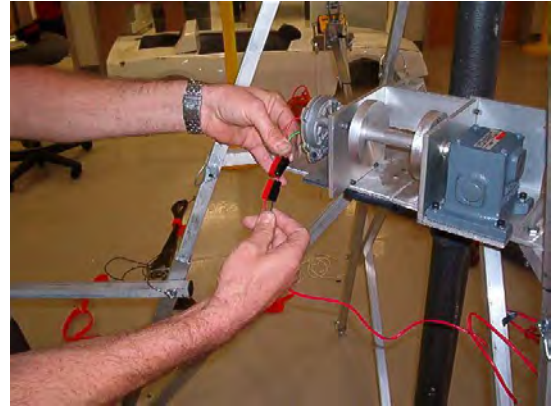
The motor will have one end of the moving platform cord permanently attached (not shown in picture). Now place the motor and the gear reducing system to the central based structure platform. Use the four bolts to secure the motor to the platform.



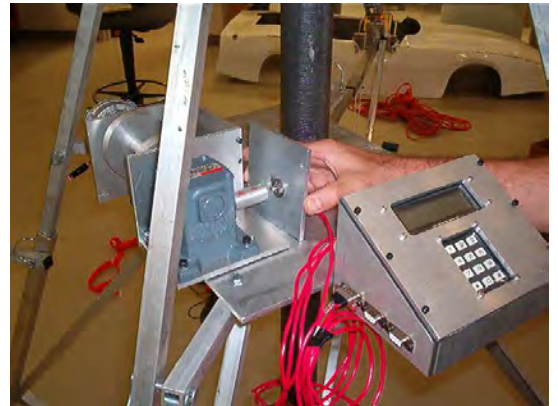
Insert the control box into the slides below the central platform, and secure with pin.



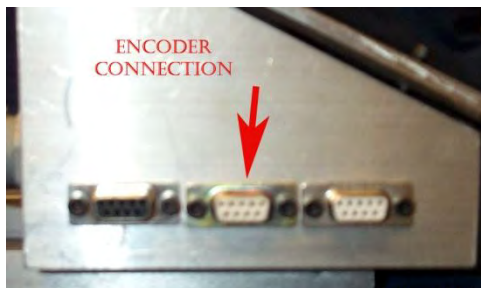
Connect the motor wires from the control box to the motor. The motor wires can be identified by the black and red connectors.



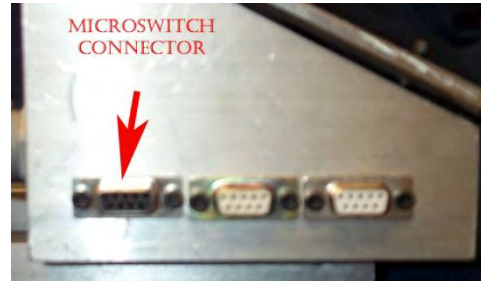
Loosely set the potentiometer plate against the gear reduction shaft. This will be completely secured later.



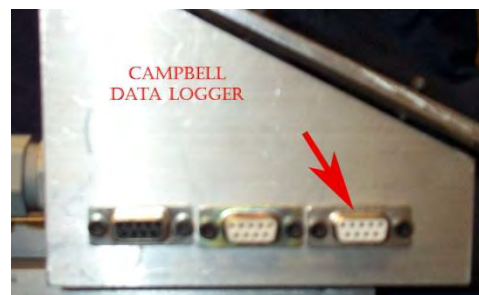
Connect the Microswitch Encoder at the tower base module to the control box (Left Location).



Connect the Campbell Data Logger to the control box (Right connector).



Connect the Encoder Connector from the gear reduction plate by the motor to the control box (Center connector).



Follow the Spooling Procedures given below – these are modified from the Operating Procedures given at the back of the document – to spool in the extra cord and to get the moving platform set.



Spooling Procedure:

All processes can be stop at any time by pressing the * key. This will reset the controller to the main menu and stop the motor.

Enter Total Height:

The control panel main menu prompts the user for the tower height (feet) as a two digit number. The # key must be pressed to accept the entry.

***Enter The Number:
Of Pipes***

Enter the number of actual pipes used to construct the tower. This is also a two digit number. The # key must be pressed to accept the entry.

Select Mode of Operation:

Select 1 for ***Continuous Mode*** then press the # key. The motor will move down to find the home position (the limit switch at the bottom of the tower). Immediately hit the limit switch so that the controller is ready to move upward.

Moving Into Position:

Attach the moving platform to the cord if this has not already been done. Press the # key to start the spooling process. Assist the cord to spool as neatly as possible. When the excess cord is taken up, be prepared to hold the moving platform as the cord begins to lift the platform so that it does not catch on the tower base. Let the platform rise to about the motor height and press the * key to stop movement.

To complete the installation of the moving platform, the two alignment cords that are attached to the top platform should be fed through the moving platform and attached to the support at the bottom of the tower.



At this point the tower raising is completed and ready for the programming of operations on the following page.

Final Suggestion: With all of the weight now on the tower, check one last time that all bolts are securely tightened, and also check again that all four sets of tensioners are tight and that the tower is as vertical as possible.

Tower Disassembly

To lower the tower, reverse the raising procedures, taking care to neatly store all components. The moving platform cord needs to be completely unspooled from the motor reel before the tower is taken down.

While the moving platform is lowering, **remove the potentiometer plate** from the gear reducer. THIS IS IMPORTANT TO NOT DAMAGE THE POTENTIOMETER. Manually move the moving platform so that it does not trigger the limit switch at the tower base. Allow the rest of the cable to spool out – you will need to assist the unspooling so that the cord does not get tangled. When it has completely unspooled, hit the * key to stop the motor, and continue with disassembly.

Operating Procedure:

Start up procedure:

***Enter Total Height:
(Feet)*** This is the main menu of the program, the user will enter the total height of the tower as a two digit number. The # key must be pressed to accept the entry.

***Enter The Number:
Of Pipes*** This is where the user needs to count and enter the number of actual pipes used to construct the tower. This number will need to be a two digit number. (Example: 6 pipes used must be entered in as 06) The # key must be pressed to accept the entry.

The ratio of total height to the number of pipes must be 3 feet or the display will prompt the user “Height Number is Not Correct” and return the user to the main screen.

Select Mode of Operation: This allows the user to select between the modes of operation:

1: Continuous Mode: In Continuous mode, the elevator will move up the tower until it reaches one foot below the top. The tower will then return to the bottom and the cycle continues until the user stops the process by pressing the * key on the keypad.

2: Time Delay Mode: The user will be required to enter the parameters that will guide the elevator to perform the heights and pause times required.

Number of Upward Steps: Enter the total number of times the elevator will need to stop along the total height of the tower. This number will be divided by the total height to the height at each stop. (Example: With a total height of 12 feet and 4 upward steps the elevator will stop at every 3 feet). This number is a two-digit number. Press the # key to accept the value.

Upward Pause Time (Sec) : Enter the total number of seconds that the elevator will need to stop at upward step. A three-digit number must be entered. (Example: if a 30 second delay is needed the user must enter 030). Press the # key to accept the value.

Number of Downward Steps: Enter the total number of times the elevator will need to stop along the total height of the tower. This number is a two-digit number. Press the # key to accept the value.

Downward Pause Time (Sec): Enter the total number of seconds that the elevator will need to stop at upward step. A three-digit number must be entered. Press the # key to accept the value.

Press Start Button: After values are entered into the system, the program then waits for the user to press the # key when the user is ready to start the process. At this time if the user thinks they have entered a wrong value into the system they can press the * key to return to the main menu.

Motor Moving to Position: The motor will move in the down position to find home position (the limit switch located at the bottom of the tower).

Press Start Button: After the elevator has found home, the program then waits for the user to reset the potentiometer. With the potentiometer removed turn the shaft counter clockwise until it stops. Now place the shaft of the potentiometer into the shaft of the speed reducer. Tighten the set screw to secure the potentiometer in place. Press the # key when the user is ready to start the process.

The process now starts with the motor moving upward to its first if time delay mode was selected or to the top of the tower if in continuous mode. Once the elevator has reached its location then the control box will output its location to the Campbell data logger.

All processes can be stop at any time by pressing the * key. This will reset the controller to the main menu and stop the motor.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 910/112732, February 2012

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA™