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National Park Service Cave and Karst Resources Management Case Study: Great Smoky Mountains National Park

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NATIONAL PARK SERVICE CAVE AND KARST RESOURCES MANAGEMENT CASE STUDY: GREAT SMOKY MOUNTAINS NATIONAL PARK

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PREFACE

This thesis is a first step towards understanding the complex nature around development and implementation of a cave and karst program on a National Park Service unit. In reviewing the literature and incorporation of policy and management guidelines specific to the needs of cave and karst resources in the Great Smoky Mountains National Park, development of a holistic karst wide management plan is shown to provide the necessary protection for caves and karst areas with caves or no known caves.

Chapter 1 provides a basic understanding and information about caves and karst environments. It also takes a look at the importance of this research and the significance to the Great Smoky Mountains National Park Management. It defines the options surrounding the use of a cave or karst focus of management. Chapter 2 takes an in-depth look at the science surrounding the understanding of cave and karst resources. It concludes with a look at management of these resources throughout history, summing up federal management as well as what has taken place within the Great Smoky Mountains National Park to date. Chapter 3 provides the process by which information was obtained from the literature, questionnaires, field investigations and consultation with cave and karst experts. Chapter 4 states the results from the questionnaires, resource inventories, and newly discovered resources. Chapter 5 provides a discussion of the implications of these results and a conclusion. It focuses on needs of the resources and the protection provided by a cave or karst driven management plan. In addition, Chapter 5 concludes with a final look at the Great Smoky Mountains National Park as a case study, and the need to develop a holistic management plan specific to its caves and entire karst landscape.

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As discussed in the National Parks Service's (NPS) Directors Orders/Natural Resources Management Reference Manual #77 and the 2006 NPS Management Policy Handbook, implementing a management plan specifically for cave and karst resources within a national park is paramount to afford these resources appropriate protection. With support from the Federal Cave Resources Protection Act and the National Park Service Organic Act of 1906, management actions protecting caves has begun to place significant importance outside the traditional cave environment onto a broader karst landscape. The need to understand and protect the karst environment and caves as a karst resource has taken a much larger role in the scientific literature and has increased interest in its federal management application. Proactive management through the use of holistic karst wide management plans and programs is shown to provide superior measures for resource protection when compared to the shortcomings associated with reactive cave focused management. The use of Great Smoky Mountains National Park (GRSM) as a case study supports the need to develop and implement a proactive cave and karst management plan specific to their resources. Management decisions with regards to cave and karst resources currently follow the park's general directives and Superintendent's Compendium. GRSM's caves and karst areas represent unique resources, such as

extensive vertical relief and rare biota, requiring special management in order to effectively protect them and to manage those who study and recreate within them. Characteristics such as these necessitate holistically addressing management of these resources.

Chapter I: Introduction

For as long as humans have inhabited the earth, cave and karst regions have provided an environment that has helped shape their culture. From the earliest evidence of human existence, humans used caves as shelters and, in some regions, honored them as sacred places (Hayden 1975). As humankind has evolved, land use patterns have as well. People exploited caves for economic gain and altered karst landscapes to fulfill the needs of civilization. What occurs today is a continued struggle between humans' progressive manipulation of caves and karst areas and a scientific understanding of the importance of protecting these rare and unique places for their irreplaceable intrinsic value.

Currently, cave and karst resource management in the United States is applied in a variety of ways through diverse methodologies not only between different land management agencies but also within agencies such as the National Park Service (NPS). No rigorous studies to date have investigated what methods maximize the successful protection of these resources. The present study, using the Great Smoky Mountains National Park (GRSM) as the setting for a case study, analyzes the differences between a karst resource or cave focused management plan, and assesses which is better for protecting resources within the institutional framework of the NPS. Holistic karst landscape-wide assessment and management covers all components of the karst ecosystem, including caves, as well as the relationships between them. A management of the karst landscape often places an important role on the subterranean hydrology which in the case of GRSM has played an important role in cave development and associated cave resource development. A policy-focused management of the cave considers the karst environment only when it is understood to have effect on the resources of the cave. This approach provides no protection to karst where caves do not exist or are unknown. Scientific literature strongly supports the need for landscape-wide karst management (Fleury 2009).

Specifically, this study addresses two research questions, including:

1) What are the challenges and benefits of landscape-scale management of karst (karst management plan) over traditional, institutionally-directed, site-specific management of cave resources (park cave management plans) within NPS managed units?
2) In order to meet the legislative mandate and guidance requirements of the Federal Cave Resources Protection Act of 1988 (FCRPA) and other relevant laws and guidance memos, what are the best practices for managing cave and karst resources on NPS managed lands?

This study works to clarify the basic need to understand how policy, best practices, and a thorough understanding of the resources are required to successfully protect cave and karst resources on NPS managed lands.

Caves and Karst Landscapes

In US federal government terminology, the term "cave" is used to define a naturally-occurring hole in the earth (vug) large enough to permit a person to enter (FCRPA 1988). From that general term, federal and state agencies in the US have scientifically described individual caves by their size, shape, bedrock type in which it formed, resources associated with it, and method of development. Caves are generally classified by their geology and most commonly fall into one of nine types (Palmer 2007). Solution caves (epigenic) are caves developed by chemical dissolution in carbonate rock including limestone ($CaCO_3$), dolostone ($(Ca,Mg)(CO_3)_2$), or marble (metamorphosed $CaCO_3$) as well as evaporite rocks such as gypsum ($CaSO_4 \bullet H_2O$) or halite (NaCl). Stream cut caves differ from solution caves because physical erosion or abrasion is the primary mechanism for development. Lava tube caves are volcanic in origin. Tectonic or crevice caves are caves often, but not solely, formed in igneous rock or clastics from tectonic fracturing. Sea caves develop from wave action on the parent material. Shelter caves form when an over-hang of less weathered rock prevails over a more soluble or otherwise less resistant rock or substrate that is removed from underneath it. Talus caves form in almost all rock types as a result of extensive colluvial deposits. Ice caves are caves formed in ice, sometimes along fractures or where run-off has created an underground passage. Framework caves form in stream deposited tufa mounds (Jones et al. 2003; Palmer 2007). The United States has several regions of caves and karst with an estimated 54,000 caves (NSS 2011). Palmer (2007) described fifteen cave regions including those in soluble rock and lava. They are spread out across most of the coterminous United States, Hawaii's big island, and into the interior of Alaska.

Karst areas are defined scientifically by Palmer (2007) as, "a terrain where chemical weathering or dissolution of typically carbonate bedrock that represents the main mechanism of erosion in such a manner to develop conduits which promote the circulation of fluids." Generally, active karst areas are characterized by having little to no surface water and the presence of caves, underground rivers, and springs where those rivers resurge. However, karst landscape development can be present with little or no surface expression visible. Well-developed karst areas are the predominant landform of ten to fifteen percent of the earth's terrain and provide drinking water for twenty-five percent of the earth's population (Ford and Williams 2007). Karst scientists suggest that the earth land area consists of approximately twenty-five percent karst areas if we count minor karst, pseudo karst, buried karst, and deep-seated solution porosity. This figure is slightly lower (~ twenty percent) for the United States (Klimchouk et al. 2000; Palmer 2007). Caves and karst in soluble limestone are products of their geology and hydrology. Simplified, the geological and hydrological component to cave development in karst is that subterranean solids must be removed faster than surface erosion can weather the bedrock around it. This occurs as the geology allows for subsurface flow of water through fissures, faults, and other networks of fractures that allow development into karst. Karst areas concentrate surface flow or flow from the water table into the karst system, further promoting karst/cavernous development (Klimchouk et al. 2000; Palmer 2007).

The focusing of both subsurface and surface flow in karst systems promotes easy and rapid transport of contaminants and foreign matter into caves and karst environments. Human impact on the surface of karst landscapes has had adverse effects on subsurface environments because the two environments are tightly linked. Almost all of the threats to cave and karst environments are anthropogenic and pose irreversible concerns for cave and karst management (Jones et al. 2003; Fleury 2009). The physical destruction of and the chemical alteration of the natural environment as well as the introduction of non-native components are often the primary threats to caves and karst environments in the US and across the planet.

Significance and Justification

A comprehensive review of legislation and assessment of "best practices" from various land managing agencies who have implemented management plans with a focus on caves and karst is pertinent to anyone seeking to protect cave and karst resources in similar conditions. As other national park units and federal land managing agencies seek to develop and implement cave and karst management plans, this research will provide an accurate account of the legislation and management of caves and karst on federal lands.

Development of a Cave and Karst Management Plan for the Great Smoky Mountains National Park is significant due to the heavy visitation this park experiences. With over nine million visitors a year, GRSM is the most visited national park in the world. The park contains significant cave resources that are within easy reach of visitors. No GRSM karst exists in remote areas of the park. All known karst areas exist less than one mile from developed roads or the park boundary. Where karst is found along GRSM boundaries, karst hydrology is important to neighboring communities as a source of recharge for their aquifers. The primary example is Dry Valley, TN, which does not receive municipal water services. In this case, GRSM karst is important to water quality and aquifer recharge as karst hydrology is continuous from the park to Dry Valley. GRSM also employs fire management practices and pesticide use on karst environments and may need to treat these areas separately from non-karst environments as contaminants could affect the karst groundwater. In all cases, karst environments have seen much human use prior to and during NPS management. The geology has played an important role in pre-park settlement, GRSM development, and road locations within GRSM due to the natural leveling of the mountain topography where karst areas are found.

Without a proper understanding and framework to deal with cave and karst resource issues, park managers are unable to make consistent long-term management decisions. It has been over twenty years since the inception of FCRPA specified a need to preserve and protect caves and its associated karst resources. The FCRPA was further supported by the Directors Orders/Natural Resources Management Reference Manual #77 (RM#77) and the 2006 National Parks Service Management Policy Handbook (MP2006) which re-iterated the requirement for cave protection. All of these directives indicate that devising and implementing cave and karst management plans is imperative to long-term, consistent management of these resources in units where they are relevant. GRSM, like many other parks, has lagged behind in developing a proactive approach to management of karst resources. Until recently, managed caves were viewed more as a nuisance in contrast to the significant resource that they represent. Without a proactive management plan for cave and karst resources, GRSM cannot provide the best protection grounded under the NPS Organic Act of 1916 and the FCRPA of 1988.

Problem Statement and Purpose

General guidelines and policies exist which describe current management objectives and techniques for caves on NPS and federal lands. What is missing is a framework for guiding managers to the proper development of a resource plan that successfully addresses the needs of a specific park and its resources. Traditionally, NPS management of karst resources was focused on a specific cave- or cave-system. However, much of the current study and science of cave and karst resource management supports a focus on the holistic characteristics and needs of the karst environment, which ultimately protects the caves, a component of karst systems. GRSM has a multi-disciplinary Resource Management and Science division to study, manage, and mitigate the anthropogenic effects that impact the diverse natural and cultural resources within the park. Lacking is any structured program that directly deals with the intricacies of karst environments. The complexities of resource management and science outside of cave and karst resources are diverse but should not justify a lack of focus on the latter. GRSM currently does not meet the guidance of the FCRPA and RM#77 which mandate the development and implementation of a cave and/or karst management plan specific to the needs of GRSM cave and karst resources. Several karst environments of GRSM are continuous, and hydrologically connected, with karst environments of communities adjacent to their boundaries. These unspecified pathways of groundwater emphasize a need to more closely examine components of karst independent of caves. Included in the need to protect caves supported through the policy and development of a management plan is a strong need to understand the karst environments and the larger role it plays both within GRSM and outside of the park.

The research described herein evaluates the science of cave and karst management best practices and evaluates differences between holistic karst-focused and more traditional cave-focused NPS management plans. For the case study, I will also augment the existing but limited knowledge of cave and karst resources in the case study area of Great Smoky Mountains National Park. This research also draws conclusions regarding effective and efficient management practices of GRSM cave and karst resources. It provides resource managers with a document that provides a framework that allows for consistency in management of caves and karst in Great Smoky Mountains National Park, pursuant to the National Park Service Mission (1916), the FCRPA, RM#77, MP2006, and Title 43 Subtitle A Part 37 under the Code of Federal Regulations. This document provides the foundation and support the park needs to develop and implement a Cave and Karst Resources Management Plan.

Chapter II: Background

Cave and Karst Landscape Science

Speleology, or the study of caves and other karst features, is a field that encompasses many disciplines (e.g., geology, biology, and hydrology). Before the mid-nineteenth century, caves were generally studied under one of the individual disciplines, and their scientific value was based on their contribution to the individual field. Edouard-Alfred Martel was an early pioneer of cave exploration and study. Martel explored, studied, and documented thousands of caves in France and around the world. Martel was the first to introduce speleology as a distinct field. His understanding of the need to incorporate all aspects of the cave environment, including surface biology and unknown hydrology, pioneered the modern day study of caves and karst as a complex resource (Klimchouk et al 2000).

A thorough understanding of what resources, processes, and concerns are relevant to a cave and karst manager requires an in-depth understanding of cave and karst science. Karst systems as a whole are quite complex with a multitude of disciplines often represented and the need to fully understand them is paramount to proper management. Many of the physical properties of caves are crucial to the diversity and survival of the biology found in these environments. Slight changes in airflow, humidity, and temperature have been linked to the demise of entire ecosystems within caves. Anaerobic microbial communities rely on these stable conditions and may be the primary producers of energy in the otherwise oligotrophic (nutrient-poor) community. Additionally, activities changing the surface properties on karst landscapes can drastically reduce the development of cave formations and even the chemical processes that cause cave development. Disruption at any level has been linked to adverse effects, which are often irreversible (NYU Website 2008).

Cave and Karst Biology

Although interest in the study of cave biota in the United States began in the late 1800s, the majority of current information has been compiled since the 1950s (Barr 1968; Elliot 2000). Cave biota exhibit unique morphology, traits associated with subterranean life such as eye and pigment loss, delicate form, and enhanced extra-optic sensory structures (Peck 1998; Culver et al. 1999; Culver et al. 2000; NYU Website 2008). These adaptations are of great interest to scientists in the study of natural selection, gene flow and genetic and morphologic changes in species (Culver et al. 1999; Culver et al. 2000; NYU Website 2008). For example, researchers in the Cave Biology Research Group at New York University's Department of Biology study cave biota in order to better understand current problems in medicine and biology. Cave vertebrates are excellent models for the study of genetics of abnormal eye development and metabolic variation, and retinal and lens defects in cave fishes are similar to those seen in humans. Cave fishes are also a classic example of regressive evolution, and although cave species have evolved independently, evolutionary changes converge towards a common theme (NYU Website 2008). In addition to morphological adaptations, obligate aquatic cave organisms have long life spans, and are therefore likely to accumulate toxins. Such organisms are highly sensitive to water contamination, and are of interest to scientists as indicators of groundwater quality (Culver et al. 1999; Culver et al. 2000; NYU Website 2008).

Cave inhabitants can be grouped into four major groups: troglobionts (and stygobionts), troglophiles (and stygophiles), trogloxenes (and stygoxenes) and accidental cave inhabitants. Troglobionts (terrestrial) and stygobionts (aquatic) are obligate cave dwellers, species which spend their entire life cycle inside caves, and have (over time) formed adaptations in order to survive life only in caves (Reeves 2000). Species of animals including fish, salamanders, insects and spiders often have adaptations such as reduced eyes and or no eyesight, loss of pigmentation, elongated antennae and increased senses of smell and touch (Peck 1998; Culver et al. 1999; Culver et al. 2000). There are over 1300 (425 stygobiont and 928 troglobiont) obligate cave species known (Peck 1998), although less than half of the obligate subterranean species in the United States have probably been described (Elliot 2000). Obligate cave fauna has the highest reported level of endemism of any taxonomic or ecologic group of organisms in the United States (Culver et al. 2003). Troglobionts (and stygobionts) are generally of greatest interest to cave biologists and managers, as they are restricted to cave habitats and are sensitive to management practices (Reeves 2000).

Troglophiles (terrestrial) and stygophiles (aquatic) are organisms that breed and live in cave environments, but are not obligate cave dwellers. They can complete their entire life cycle in a cave, but they can also do so in other environments. An example would be the Cave Salamander (*Eurycea lucifuga*), which has been found to forage outside of caves. Trogloxenes (terrestrial) or stygoxenes (aquatic) are transient cave dwellers, they spend a portion of their life cycle in caves, but they must also leave the cave for some aspect of their life. For example, the federally listed endangered Indiana bat (*Myotis sodalis*) uses the constant environment of specific caves to hibernate through the winter. Trogloxenes often play important roles in bringing nutrients into caves. Accidental cave inhabitants cannot survive to reproduce in caves. They are often poorly adapted to cave environments witch often results in their visits being fatal.

The study of karst biology is not as focused in the literature and covers a wide array of speciation due to the epigean (above ground) component to it. The broader approach to management-managing karst systems rather than individual caves- can be a strong component to ecosystem protection. As information is collected on caves, as a component of karst terrain, protection of the larger karstic region is essential to the protection of biological resources observed in caves (Hamilton-Smith 2007).

Karst Hydrological Resources

In a karst environment, normal surface drainage basins and concepts are coupled with subsurface conduit development and flow paths to produce a complex mechanism of fluid and sediment transport. In general, karst environments are typified by sinking streams, caves, and sinkholes. The tendancy of the karst environment to rapidly transport water and associated minerals, nutrients, and pollution through the subsurface must be considered as a management concern. As mentioned, the complexity of karst environments adds to the importance of fully understanding the processes and flow paths that define the karst area. Rapid water flow through karst has the ability to move pollution across large areas quickly through subsurface conduits and require that management place importance on protecting these environments as well as understanding them. Disruption of karst flow paths can also cause surface collapse, sinkhole formation, sinkhole flooding, and other processes that affect surface and subsurface resources. (Gillieson 1996; Jones et al. 2003).

Mineralogical Resources

Mineralogical resources of caves often refer to the speleothems, or cave formations, which develop after the cave formed through a variety of chemical processes. Moore (1952) defines speleothem as "a secondary mineral deposit in a cave". Spelothems are often used to judge the aesthetic quality of the cave, especially historically when visitation to caves was based on the quality and numbers of speleothems present (Hill and Forti 2007). More recent interest in speleothems has surrounded their long growth period and their ability to shed information on the earth's environment long ago. Past conditions and changes such as sea level fluctuation, climactic/environmental differences, tectonic movement, and earthquake and volcanic activity information can be obtained from past periods preserved within the mineral deposits of speleothems. The stable environments of caves have helped preserve these records of time and additional studies continue to reveal their hidden information. The interest and need for protection has continued to grow as more scientific demand for them and their value increased (Hill and Forti 1997).

Paleontological and Cultural Use of Caves

Caves are a rich source of paleontological and archeological information, as cave environments provide protection and preservation of these oftentimes fragile resources from harsh surface conditions. Although not as extensive in North America as other cave regions in the world, cave paleontology and archeology have been sources of considerable information advancing the science of understanding the past. For example, cave archeology has shed light on aboriginal activity and specifically aboriginal cave use (Jones et al. 2003; Crothers et al., 2007). In the US, cave archeology has been dated back 4,500 years but not to the extent of the rich cave art of Europe. It appears that Native Americans did not venture deep into limestone caves with the exception of a few sites. One location is Mammoth Cave, Mammoth Cave National Park, where visitation took place during the Archaic Period around 4,000 years ago. Documentation of consistent use by Native Americans through the Woodland Period (1000 BC to 500 AD) as burial locations shows the spiritual value placed on caves.

Through much of the US, caves have played an important role in the paleontology record. These fossil records have been reported from primarily the Upper and Middle Pleistocene eras although older cave and karst associated deposits also occur. Caves (in carbonate rock) and their alkaline environments make for good preservation of a variety of fossil materials including bone, feathers, chitin, and shell. Many paleontological locations in caves have developed around “natural traps” where animals or sediment with animal remains have been captured and protected within the confines of the caves stable environment (Jones et al. 2003).

History of US Cave and Karst Protection and Management

For many years before organized cave conservation, commercial cave management and tourism created a sense of value for caves. This value is what promoted the need to provide protection for a particular cave and thus shield it from some of the resource damage that befell otherwise unprotected caves. The commercial cave owner had an experience to sell. If that experience was harmed by broken formations or otherwise objectionable circumstances, the value of the cave would be reduced and the owner left with nothing to gain from an otherwise useless hole in the ground. This is the beginning of cave management in the United States and certainly the first major modern-day interest in protection of caves. This type of management is necessarily spotty in both space and time, because it depends on the situation at specific show caves.

The twentieth century brought considerable governmental and public interest in preservation of unique and wonderful areas. The 1903 establishment of Wind Cave National Park marked the first national park set aside primarily based on its cave resources. The Antiquities Act of 1906 was intended by Congress to quickly give presidential authority to conserve historic and pre-historic areas as federal lands by developing national monuments under the Department of Agriculture-United States Forest Service (USFS) without the need of the Congressional processes. This approach, used in a variety of ways outside of historic and pre-historic preservation, afforded protection of several cave environments such as Jewel Cave National Monument (NM) in 1908 and Oregon Caves NM in 1909. These monuments, combined with the earlier establishment of Wind Cave National Park (NP), became the United States Government's first involvement in the management and conservation of caves (Wind Cave National Park Website 2008).

The inception of the National Park Service (NPS) through the Organic Act of 1916 pulled together the Department of the Interior's (DOI) previously non-centralized management of national parks. This Act laid the foundation for management of these areas by the National Park Service. By 1916, the public's interest in caves was finally united with the mission of the NPS, to preserve and protect unique places for future generations (Wind Cave National Park Website 2008).

It was a long time after national parks (like Wind Cave and Carlsbad Caverns) or national monuments (such as Jewel or Oregon Caves) were set aside by the federal government for the uniqueness they possessed that the term “cave” and the complex resource this implied would reach a level that would afford some of the highest protection of any federally managed resource in history. This transformation was slow based on an inability of many natural resource managers to comprehend the intricacies of cave and karst systems and cave management. The U.S. Fish and Wildlife Service (USFWS) helped this process along the way through their responsibility and involvement in protecting species that had shown enormous decline due to alteration and disturbance of preferred habitats. All federal agencies are prohibited from authorizing, funding, or carrying out actions that "destroy or adversely modify" threatened and endangered (T&E) species’ critical habitats (Section 7[a] [2] of Endangered Species Act [ESA] of 1973). Inadvertently, because of their role as hibernacula and maternity roosts for many species of bats, caves were afforded protection by one of the strongest environmental acts ever passed by Congress. Preceded by the Endangered Species Preservation Act of 1966, the ESA act placed protection on “listed species” and “habitat” to prevent their extinction. As several species of bats had shown large population declines, caves possessing these bats became highly protected by the ESA as a means of habitat/species protection. Additional significances of caves became apparent by further study of cave environments which has revealed numerous endemic cave species. With already reduced or rapidly degrading habitat in many of these caves, these species were federally listed imposing ESA regulations on the cave as critical habitat.

The Archaeological Resources Protection Act (ARPA) of 1979 created another tool that quickly strengthened and enforced protection of certain caves. The use and significance of caves to Native American cultures was known for some time, dated by governmental protection back to the Antiquities Act of 1906. Thousands of years of human occupation has resulted in archaeological specimens; some preserved under many feet of cave regolith that were excavated by professionals and unfortunately, artifact peddlers. ARPA was passed to protect these pieces of Native North American culture and their sacred symbolism. Caves on federal property, and to some extent private property, which were known to contain these artifacts or that were sacred to Native American groups, were afforded protection from looting.

The development of the Federal Cave Resources Protection Act (FCRPA) of 1988 was a response to the inconsistencies within management of caves on federal lands under the jurisdiction of the Departments of Interior (BLM-Bureau of Land Management, USFWS, and NPS) and Agriculture (USFS). Partially driven by cavers, the act pulled together management approaches making them consistent across agency and departmental boundaries (Stitt 1994). These management approaches were mainly modeled after those used in (at least parts of) the National Park Service. Much of the protection the FCRPA provided was already being incorporated by some agencies based on their missions and goals, but was not common management practice for all aforementioned federal land agencies. The act is designed to preserve and protect all significant caves on DOI (BLM, NPS, and USFWS) and DOA (USFS) managed federal lands for the benefit, enjoyment and perpetual use of all the people. It promotes cooperation and information exchange between governmental authorities and those who use caves on federal lands for recreation, educational, and scientific purposes. The FCRPA has within it one additional provision, that the Freedom of Information Act is not to apply to cave locations. Therefore, federal cave locations are not considered public information and should not be disclosed to the public. The addition of this provision clearly shows the importance of cave and karst resources and the need for recognition of their value across agency missions.

One of the purposes of the FCRPA was to foster increased exchange of information and cooperation between agencies mandated under it. A strong working relationship between these agencies had already existed, but no formalized agreement was in place. In 2003, signatures from the Bureau of Land Management, US Fish &Wildlife Service, National Park Service, United States Geological Survey, and the US Forest Service finalized an agreement intending to achieve more effective and efficient management of caves and karst on federal lands. This agreement is meant to identify mutual concerns and establish mechanisms for cooperation and collaboration in the management, protection, conservation, and research of caves and karst resources, specifically on lands managed directly by these agencies. The agreement addresses several needs; as all units involved protect and utilize land based on the needs of the public, there is a necessity for uniform management of cave and karst resources to ensure consistent service is provided to the public (Bailey 2001; BLM Cave and Karst Program Website 2011).

The Lechuguilla Cave Protection Act of 1993, another cave-specific act, emphasizes the importance of cave preservation across federal agency boundaries by extending protection to the surface above the known and possible extent of the underground portions of this specific cave. This cancels mineral and thermal permits associated with adjoining federal lands within the Lechuguilla Cave Protection Area. Although this act does not directly affect any one cave other than Lechuguilla Cave in Carlsbad Caverns NP, it could affect federally managed lands with caves by creating precedence for cave protection beyond that of agency missions and agency boundaries.

In 1990, Congress directed the Secretary of the Interior, acting through the Director of the Park Service, to explore the feasibility of a centralized cave and karst research program. Known as the National Cave and Karst Research Act of 1998 (NCKRA), this act led to the establishment of the National Cave and Karst Research Institute (NCKRI). NCKRI, is mandated to advance cave and karst science by conducting, coordinating, and facilitating research, education, and partnerships (NCKRI Website 2008). Temporarily under the NPS, NCKRI has recently reorganized as a non-profit corporation with three primary partners: the National Park Service, the City of Carlsbad, and the State of New Mexico through the New Mexico Institute of Mining and Technology (aka NM Tech) (NCKRI Website 2008).

Additional acts (e.g., state cave protection laws) have also played roles in the protection of caves and associated environments (Huppert 1995). Twenty-seven states have cave-specific laws affording protection for cave resources. Some state laws protect in conjunction with rare species while almost all afford protection against physical destruction of the cave and its resources (Lera 2002). With ample legislation in place, a foundation has been set to protect and research caves and their specialized environments on federal lands.

Federal Cave and Karst Management

Federal Land Managing Agencies Bound by FCRPA

The United States Government manages approximately 650 million acres of land (twenty-eight percent of the Unites States land mass) (National Atlas Website 2011). Land managing agencies vary considerably as to what are considered by each agency as management goals. These management goals are dependent on the mission that each agency is required by statute to meet; as each agency's mission has been developed to manage their land in a particular way for the greater good of the country.

The largest land-managing agency within the US federal government (in terms of acres managed) is the Bureau of Land Management (BLM) under the Department of the Interior (DOI). BLM manages approximately 261.7 million acres, roughly one-eighth of the landmass of the country. BLM is nearly absent in the east but widespread throughout the western United States and Alaska. This agency's mission is to sustain the health, diversity and productivity of the public lands for the use and enjoyment of present and future generations. Large portions of BLM lands support mineral and timber extraction leases across their managed lands. The BLM manages nearly 800 caves in eleven states (BLM Cave and Karst Program Website 2011).

The Unites States Forest Service (USFS), under the Department of Agriculture (DOA), manages 193 million acres in the form of 155 National forests and 20 National Grasslands. The mission of the USDA Forest Service is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. National Forests provide sustainable forest products, mining leases and recreational opportunities across the country (USFS Website 2011).

The United States Fish and Wildlife Service (USFWS), under the DOI, manages approximately 96.4 million acres of land in the form of roughly 545 National Wildlife Refuges and approximately another ninety districts and areas. National Wildlife Refuge System Administration Act of 1966 identified lands under which the USFWS was to manage for the protection of wildlife and wildlife habitat. Their mission is working with others to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people (USFWS Website 2011).

The NPS, under the DOI, manages approximately 84.6 million acres in the form of 391 units, fifty-eight of which have national park designation. Over 4000 caves have been identified from eighty-five NPS units (Ek 2005). The NPS mission is:

"*...to promote and regulate the use of the...national parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*."

NPS policy also states that all caves within their management are significant and thus will be managed to their fullest protection (FCRPA 1988; NPS Website 2011).

At 66 million acres the Bureau of Indian Affairs (BIA), under DOI, manages a substantial amount of land. Not all the land is managed for public use; within the lands, management varies significantly based on resources and needs. Although cave protection is provided through several acts of congress, the FCRPA does not apply to BIA lands and thus provides no protection to caves they manage (BIA Website 2008). It is important to note that additional tracts of federal land are managed by agencies that do not fall under the jurisdiction of DOI or DOA, and therefore are not bound by FCRPA. That does not imply that cave resources are not considered in land management. For example, the Department of Defense (DoD) manages over twenty-five million acres, and Department of Energy 2.4 million acres. Significant cave resources fall under management of each of these agencies. The DoD's Legacy Program has assisted in identification of eighteen new cave species from two Army bases in Texas. Close to one million dollars was spent over twelve years to find and research caves and cave fauna at those two bases (Elliott 2005). Tennessee Valley Authority manages over 293,000 acres, and has known cave resources. When the FCRPA does not apply, cave protection is often afforded under the ESA.

Federal Cave Management and the National Park Service

With the development of the FCRPA, its bound federal land management agencies under both the Department of the Interior and Department of Agriculture are required to inventory and list significant caves on federal lands and to provide management and dissemination of information about caves. In 1998 Congress passed the National Cave and Karst Research Institute Act of 1998 in order to further promote cave and karst research. In addition to these broad federal regulations regarding cave and karst management, the National Park Service is also guided by more specific legislation such as the Lechuguilla Cave Protection Act of 1993. In order to fulfill these obligations, federal land management agencies are continually devoting increased resources to karst management, as concepts and practices in cave and karst management continue to evolve.

The NPS's cave management falls under the advisory of the Cave and Karst Program. One-hundred and twenty park lands have identified cave and karst features, with eighty-five containing caves. Under the FCRPA and CFR Title 43—Public Lands: Interior, Part 37 - Cave Management, the NPS designates all caves as significant caves and manages accordingly (Ek 2005; NPS Cave and Karst Program Website 2011).

NPS resource managers are guided in managing, protecting and conserving all natural resources in their unit by the NPS's Director's Orders guidance; Natural Resources Management Reference Manual (RM#77). The guidelines under RM#77 specify the policy and program directives, the authoritative legislation, methods of protection and fulfillment of legislation, as well as an explanation of the roles and responsibilities of those who are in position to manage caves and karst.

Within the NPS's RM#77, the Cave and Karst Management section provides guidelines for the management of caves, encompassing the many disciplines necessary to protect and perpetuate natural cave systems. Guidance is oriented towards the needs of anthropogenic challenges within caves ranging from resource planning for karst protection to direct management of developed caves (as in "cave parks", such as Mammoth Cave [MACA] or Carlsbad Caverns National Park [CAVE]). It is stated that parks with small, undeveloped caves should adapt and apply relevant management as they see fit for their conditions. Management of caves includes protection of soils, surface landforms, natural drainage patterns and hydrologic systems, and cave microclimate and ecosystems (RM#77). Although NPS units with cave resources are mandated by RM#77 to develop and implement a cave management plan, many currently do not employ cave management plans.

Several NPS units employ cave and/or karst specific management plans for optimal management. Several of these provide developers of management plans an understanding of concerns and needs to make plans effective and efficient. Plans from CAVE (2006), Grand Canyon NP (GRCA) (2007), Sequoia and Kings Canyon NP (SEKI) (1998), Timpanogos Cave NM (TICA) (1993), Cumberland Gap NHP (CUGA)(1998), Wind Cave NP (2007), and Jewel Cave NM (JECA)(2007) are good sources of information applicable to most managers in developing specific cave and/or karst specific plans.

NPS Cooperative Relationships

The NPS has a Memorandum of Understanding (MOU) with the National Speleological Society (NSS) for the purpose of support and encouragement of the NSS's involvement in the inventory, scientific study, management, planning, and protection of cave resources on agency-administered lands. In accordance with this MOU, the NPS will provide access to caves under their management, advise opportunities for cave related studies and projects, advise of NPS research and cave management policy, assist to develop and implement a safety programs and search and rescue plans for the cave and karst related projects/studies, and acknowledge the work products and data gathered by the NSS. There is also a specific MOU with the Cave Research Foundation (CRF) to facilitate project development where they are the primary collaborator for in-cave scientific research.

The American Cave Conservation Association has an MOU with the NPS to foster stewardship relationships with commercial cave interest in National Parks. They also have worked to define guidelines and assistance for cave gating projects. In addition, Bat Conservation International (BCI) works within an MOU with the NPS to provide guidance, support, and protection of bats in the US. These MOUs as well as others all foster protection to cave and karst related resources within the NPS.

As mentioned earlier, there is also an *Interagency Agreement for the Collaboration in Cave and Karst Resources Management* between the NPS, USFWS, BLM, USGS, and the USFS which addresses a need for collaboration to achieve efficient management. The purpose is to achieve a more effective and efficient management of caves through their cooperation in understanding mutual concerns and avenues for better management. This need for cooperation fulfills the FCRPA and NCKRA requirements for exchange of information and cooperation (BLM Cave and Karst Program Website 2011).

NPS Cave and Karst Outreach

The NPS has a comprehensive website that provides information to the general public, teachers, and scientific readers. The role of the NPS Cave and Karst Program in the management of caves and karst is explained with the emphasis on stewardship, responsibility, science, cooperation, coordination, and education. The importance of, threats to, and management of NPS cave and karst resources are described within the broader framework of other federal agencies' cave and karst management and programs. Various NPS units have successful outreach programs, as well, describing the importance and protection of cave and karst areas in their park and managed within the NPS. In 1998, the NPS developed a newsletter as an avenue for NPS cave and karst managers to share ideas about the management of cave and karst resources. Called the *Inside Earth*

Newsletter, topics discussed range from wilderness cave management to major construction within tourist caves (NPS Cave and Karst Program Website 2008).

NPS Cave Management in Practice

The NPS units that have extensive cave systems demonstrate considerable effort towards achieving the goals that the NPS has placed on cave and karst protection and management. The longest known cave in the world, Mammoth Cave, in Mammoth Cave National Park (MACA), works with neighboring communities to protect the fragile system that extends beyond the parks borders. MACA's (2006) Water Resources Management Plan delineates much of the hydrology of the karst systems within MACA and the areas outside the park contributing to the recharge of the systems. Extensive monitoring and dye tracing has allowed for the establishment of proactive protection in the event of a toxic discharge that could potentially affect the karst water quality. The efforts placed in development of cooperative relationships with state, county, and city management have been a great step toward MACA's comprehensive protection of their underground environments (MACA Water Resources Management Plan 2006).

Management staff at Wind Cave National Park (WICA) use spatial data, in the form of cave survey data, in GIS to better identify relationships between Wind Cave and other caves both in and outside of the park. These data have also been joined with geologic data to create a cave potential map for Wind Cave, showing areas with the highest potential for unexplored, developed cave passage. Combining known and potential areas of cave passage with the historic and present water table and geologic feature data, models of likely maximum potential cave length can be calculated (Horrocks and Szukalski 2002; Ohms and Reece 2002). In addition, WICA used GIS to better understand the spatial relationship between a proposed remodeling of the visitor center parking lot in order to incorporate a runoff treatment system to decrease impact to the underlying cave system (Ohms and Reece 2002). Similar methodology was used at Jewel Cave National Monument (JECA), were GIS facilitated the prevention of the introduction of herbicide into the underlying cave system. Invasive species data was compared to spatial analysis of potential infiltration points into the cave system to prevent contamination of the in cave fauna. JECA also manages their spatial data of cave location to accurately determine the cave's extent outside of the monument boundary onto United States Forest Service (USFS) land. This allows JECA to work cooperatively with the USFS and their spatial data to protect the known 40% of Jewel Cave that exists beneath land under USFS management. In addition to identifying the location of known cave passage, JECA's spatial data has been used to show a direct relationship between passage trend and identified geologic faulting. The further use of these data could be the development of a model showing the potential areas of undiscovered passage along known or predicted fault lines (Ohms and Reece 2002). At both WICA and JECA, GIS allows for management of extensive data for practical management of cave and karst resources.

The Cave Management Plan for Hurricane Crawl Cave, Sequoia Kings Canyon National Park (SEKI), was first developed in 1992. It was revised in 1998 to further protect the exceptional resources, including unusual cave formations, likely endemic species and paleontological remains. The cave management plan restricts access to portions of the cave, closing trails through highly sensitive areas. SEKI recently completed a GIS-based analysis and review of protection to speleothems, paleontological specimens, and biota based on proximity and use of established trails. The review supports current management techniques (e.g., trail closures) for the protection of speleothems and paleontological entities, but does not support the management techniques employed by the NPS in an effort to protect biological entities. The incorporation of GIS allows for reevaluation of management techniques (Despain and Fryer 2002).

Great Smoky Mountains National Park

General

The Great Smoky Mountains, a sub-range of the Appalachian Mountains, extend along the Tennessee and North Carolina border (Figure 1.). The majority of the range is protected in the GRSM. The land encompassing the GRSM is managed and maintained under direction of the National Park Service (NPS), United States Department of the Interior (DOI). GRSM has exclusive federal jurisdiction, meaning that federal law prevails over local and state jurisdiction. The park itself is bordered to the north by the Valley and Ridge Province of the southern Appalachians and to the south by the Blue Ridge Mountains. The exposed rock of the primary geology of the Appalachian Mountains is some of the oldest of any mountain range on the planet. The Smokies range is comprised mainly of members of the Ocoee Supergroup: Precambrian metamorphosed sandstones, phyllites, and slate with the oldest members being gneiss, granite, and schist. Secondarily, the northwestern movement of the Smokies range, in the Allegheny orogeny, thrust the older metamorphic rock over the younger carbonate rocks of the Upper

Cambrian and Lower Ordovician resulting in the current Smokies geology (Moore 1988; Houk 1993).

GRSM was created in 1934 as the largest national park in the eastern United States. It is also the largest national parks in the country whose land had to be purchased from private ownership for the inception into a national park. GRSM is an International Biosphere Reserve with 150 square kilometers of old growth forest and the largest continuous tract in the eastern United States. Its forest communities (from 250 to over 2000 m above sea-level) encompass species diversity representative of typical forest communities from Georgia to Maine. In addition to being designated as an International Biosphere Reserve, the park is also a World Heritage Site based on its scenery, biology and geology. The park maintains seventy-eight historic structures, ten of which are listed on the National Registered of Historic Places, representative of southern Appalachian Mountain communities. An All Taxa Biodiversity Index (ATBI) is being conducted in the park. To date 12,000 of an estimated 100,000 species (twelve percent) have been formally identified, exemplifying the importance to continue study and understanding of the Smokies to preserve and protect it for future generations (Discover Life in America [DLIA] Website 2008). The diversity of almost every aspect of the Smokies contributes to the diversity of every other component. If not for the intertwined complex geology, representative forest types, altitudinal ecotones, diverse speciation, distinct seasons, rich culture and heritage, the Smokies community would not be what it is today. The interdependence among each component of the Smokies exemplifies the need to preserve and protect all aspects of the Smokies. Included in this should be rare and unique cave and karst resources.

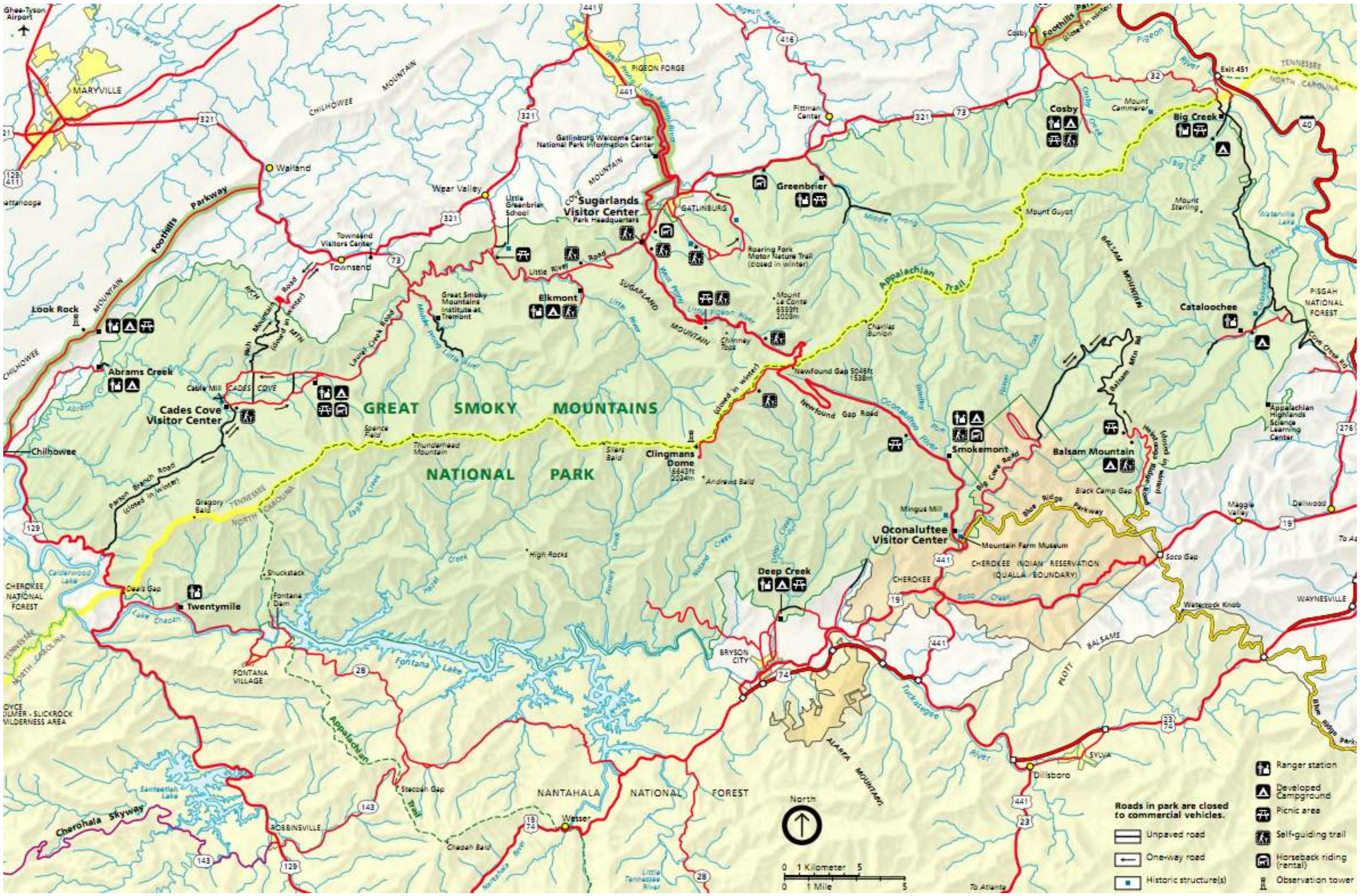

Figure 1. Great Smoky Mountains National Park, North Carolina and Tennessee

Great Smoky Mountains National Park Cave and Karst Management

Current management of cave resources is not based on an approved management plan for caves and karst. Two GRSM Draft Cave Management Plans (1979; 1989) were developed, but their implementation has been limited due the fact that they were incomplete and inaccurate. The first attempt at developing and implementing a proactive cave management plan occurred in 1979 but this plan was never completed. At a later date that draft was repurposed as an “Indiana Bat Management Plan” and focus on resources other than the Indiana bat was limited. It too was never completed and offered no additional guidance on cave/karst resources. Following the development and inception of the FCRPA in 1988, GRSM developed another draft management plan (1989) that was little more than an updated draft of the 1979 version. It incorporated additional caves but was never completed and in its current form is less useful due to omissions of resources from the 1979 version. Currently, reactive management decisions in regards to cave and karst resources follow general NPS directives and the park's Superintendent's Compendium.

Caves and Karst Areas of the Great Smoky Mountains National Park

The Park recognizes twelve solution caves in the Cades Cove District of GRSM. As early as the 1930s, park managers expressed an interest in better understanding the cave and karst areas in the park. Early efforts to describe the park's caves were focused on describing the geology and physical conditions inside the caves (GRSM 1936). In addition, early geologic surveys helped define areas of the park where karst topography was present. As the knowledge and focus of park biota increased, researchers began to recognize a slightly different biology in what would later become identified as karst areas. As biological research progressed throughout the park, focus was primarily on the high-ecological communities and not on the low elevation area which include the known karst and caves. One exception was an interest in stream ecology in Cades Cove (GRSM *No Date*). As time progressed, specialist including cave scientists began to look at the diversity and uniqueness of GRSM caves and karst areas. In addition to solution caves, which have formed in the karstic areas of the park, the Tennessee Cave Survey shows several caves in non-carbonate bedrock within the park. These caves are mostly along the steep slopes of Little River Gorge. Caves such as these will not be in the focus of this study although management might be similar as their resources are better defined.

Geology and Hydrology - Geomorphology

Karst areas within the GRSM exist in the western portion of the Tennessee side of the park (Southworth et al. 2003). The karst systems in GRSM form in fensters of calcium carbonate in the Great Smoky Mountain thrust sheet. The older metamorphic rocks (Ocoee Supergroup: Snowbird Group-Metcalf phylitte and Great Smoky Group-Cades sandstone) that make up the Great Smoky Mountains were thrust over much younger limestone and dolostone (dolomitic limestone) of the upper Knox group (Paleozoic, 500-450 million years ago) along the Great Smokies Fault (Wilson 1935; Neuman 1947; King et al. 1968; Southworth et al. 2005). Erosion of the metamorphic rock exposed the underlying limestone and dolostone, forming fensters, the grassy valleys typical of the Valley and Ridge Province of the Appalachians. It is in the walls and floors of these valleys where karst topography and subsequently caves formed (Barr 1961;

GRSM 1989). Locally, the Jonesboro limestone is massively bedded and brecciated Mascot dolostone of the Kingsport (Mascot-Kingsport) formation (Haygood 1969). Because they often form along tilted bedding planes and/or the Great Smokies Fault, caves in the GRSM tend to exhibit high vertical relief. This is especially true for most caves in the Rich Mountain and White Oak Sink areas.

Cades Cove is typical of a fenster with steep sides and flat bottom. The Cades Cove area, if it was its own National Park, receives enough visitation (~two million visitors a year) to rank in the top ten national parks with respect to the amount of visitation. Drainage of Cades Cove is via Abrams Creek making it the only karst area managed by GRSM that does not drain into the Little River Drainage. Cades Cove also has several ecologically important sinkholes, which retain water during wet periods. There are two known caves in the Cades Cove area. Through the vegetation management program, the park employs yearly burning and mowing to maintain open fields and native grasses within the cove.

The Rich Mountain karst area is a peripheral uvala or large sink (Bull Cave Sink) of the greater Tuckaleechee Cove fenster (Jonesboro limestone). The base of the sink drains into the Bull Cave System, one of five known caves with entrances in the sink. This is an active karst area whose drainage is thought to recharge ground water in the Dry Valley area outside of the park. This sink is easily accessible and is the home to two of the deepest caves in the eastern U.S.

White Oak Sink karst area is also on the periphery of the Tuckaleechee Cove fenster. White Oak Sink is a very large uvala whose karst is continuous with that of the Tuckaleechee fenster, but is isolated somewhat by the elevation differences. White Oak

Sink has several active karst openings; on the floor of the sink are two of the 4 known caves that have openings within the sink's elevated rim. According to internal National Park Service Natural History files, prior to park establishment, an attempt was made to trace the drainage path of water from White Oak Sink, GRSM to Dunn Springs, Dry Valley, TN. Sawdust was placed in one of two caves in White Oak Sink (likely White Oak Blowhole or Rainbow Cave), and allegedly surfaced at Dunn Springs approximately ten hours later (GRSM *No Date*). White Oak Sink is easily accessible, although the NPS does not maintain trails to the sink area.

A small karst window in an early stage of development exists in the Big Spring Cove area. This area is typified by several sinkholes (< ten meters in diameter) that do not permit quick drainage of surface water into the underlying Jonesboro limestone. King, in 1951, drilled test holes to determine the depth at which carbonate rock existed below the surface. Carbonates were encountered at approximately 15m below the surface (King 1964). The existence of sinks show that karst in this area is active but remains covered by weather resistant non-carbonate rocks. There are no known caves in this area (Southworth et al. 2005).

Lastly, the GRSM manages a narrow strip of land around the Tennessee side of the park designated as the Foothills Parkway System. Not all of the parkway is complete at this time. Funding for completion of the next portion of the Foothills Parkway (from Walland, TN to Wear Cove, TN) has been sporadic and completion could take place in the next ten years. The remaining sections (Wear Cove to the Gatlinburg Spur and onto Cosby, TN) are in preliminary development stages. This road corridor crosses several large karst windows; one cave is known from this right-of-way in the Wears Cove fenster

(Jonesboro limestone). In 1990 a groundwater dye trace study was done in conjunction with early survey development of the Foothills Parkway System in Wear Cove to assess potential impacts to water quality in GRSM's Stupkas (Myrh) Cave. (Beck and Herring 2001).

Archeology and Cultural Resources

Limited information has been published on the archeology and cultural resources associated with cave use in Great Smoky Mountains NP. Historical accounts of use of park cave and karst resources include saltpeter and surface mining, speleothem removal, storage, commercial tourism and recreational use. Park archeologists speculate prehistoric use of several park caves (GRSM *No Date*). Paleontological information on GRSM caves does not exist in GRSM literature. There has been recent interest by university professionals on the subject in conjunction with paleoclimate studies but no comprehensive exploration has been attempted or documented.

Biology

The southeastern United States, including the Appalachian Mountains, exhibits significant diversity of obligate cave fauna (troglobionts and stygobionts). In addition, Tennessee, in which all of Great Smoky Mountains National Park's caves and karst areas lie, is the fourth most diverse state in regards to genus-level diversity of obligate cave fauna (Peck 1998; Culver et al. 1999). Great Smoky Mountains National Park is one of the most biologically diverse places in the world. Designated as an International Biosphere Reserve in 1988, the park is home to 12,000 known species, and scientists estimate there are 88,000 species yet to be identified and described (NPS Website 2008). Although the park lies in one of the most diverse regions and states in regards to obligate cave fauna genus and species richness, park managers are just beginning to work towards a comprehensive assessment of the distribution of obligate cave fauna and rare epigean biology of the cave and karst areas within the park boundary.

In 1974, GRSM began studying human impact and restricting access to park caves because of the presence of Indiana bats (*Myotis sodalis*), a federally protected species (GRSM 1979; Rabinowitz and Nottingham 1979). Currently, the only continuous monitoring of any cave biota is conducted in conjunction with the United States Fish and Wildlife Service's Indiana bat Recovery Plan's hibernacula counts. These counts occur every two years in one cave in the park. It was not until the early 1980s that there was a concerted effort to identify and describe specific species associated with caves and karst. Beginning in 1984, under the direction of Great Smoky Mountains National Park resource managers, Richard L. Wallace completed a series of biological survey reports of the Great Smoky Mountains National Park's caves. Although there existed data on bat fauna that occurred within the park's caves, Wallace noted that knowledge of other cave fauna was "incomplete or unknown". Wallace's biological surveys uncovered several new, rare and endemic species as well as a new location for a threatened and endangered species (Wallace 1984; 1989; 1990).

Based on Wallace's findings, park resource managers began monitoring populations of cavernicoles (*Stygobromus fecundus*) in at least one location, Gregorys Cave (Johnson 1991). Management of Gregorys Cave was changed in order to provide protection for this endemic species. Without continued interest and direction through a cave management plan, over time, the monitoring efforts have fallen by the wayside with occasional spot checks by visiting scientists. Several independent researchers have surveyed a variety of cave and karst associated biota in the caves of Great Smoky Mountains National Park: amphibians (Dodd and Griffey 2001; Dodd 2003), salamanders (Taylor and Mays 2006), spiders (GRSM 1992; Paquin et al. 2009), annelids (Reeves and Reynolds 1999), and general invertebrate cavernicoles (Reeves 2000). In addition, in 2006-2007, DLIA, a non-profit partner of the national park invited scientists with a specific interest in karst areas to participate in a “Karst Quest” to identify and describe both cave life and associated epigean biology related to the karst areas in the park (DLIA 2007).

The abundant and diverse flora and fauna associated with caves and karst areas in the park have garnered increasing interest from researchers and visitors alike. For example, White Oak Sink is a very popular off-trail hike in the Smokies; in recent years, interest in wildflower diversity has caused visitation in the spring to reach unmanageable levels.

Great Smoky Mountains National Park's *Cave Management and Management of Threatened and Endangered Indiana Bats* (GRSM-N-16 1979) states that “Given the unique character of the above-ground environment, there is good reason to believe that a thorough survey and analysis of the underground environment will uncover additional unique and rare biota and minerals”. In addition, caves with significant vertical development, like that of the Smokies, are likely to exhibit higher species diversity than caves with extensive horizontal development (Culver 2003).

Chapter III: Methodology

Federal Policy and Literature Review

This study evaluates current best practices surrounding federal cave and karst management. More specifically, how are federal land managers (such as from other NPS units) are meeting or falling short of the requirements under the FCRPA and the NPS's RM#77 by incorporation of management tactics through a proactive or reactive management focus. Specific to this study is an evaluation of how management varies through holistic karst terrain management, observed in current scientific literature, and cave centered management derived from the primary driving policy. These two approaches were evaluated for application to GRSM needs. Using GRSM as a case study, recommendations for appropriate protection of key resources is based on the application of these two directions.

A comprehensive review of the literature, both from the scientific, as well as management side, provided a strong understanding of where the two disciplines overlapped in the field of cave and karst management. The evaluation of published articles, texts as well as management plans, guidelines and policy provided a strong background in evaluating GRSM cave and karst resource needs. Participation in NPS and federal level seminars and symposiums provided opportunity to develop solid relationships with cave and karst specialists, and karst related scientist who provided feedback on GRSM management options. With a primary focus on development and implementation of structured protection for GRSM cave and karst resources, collaboration on projects outside of GRSM in several National Parks and US Forests provided insight to their approaches. In all aspects the relevance and application to GRSM were sought and considered.

Land Managing Questionnaire

After completing the review of the literature on existing practices by federal land management agencies as well as the science pertaining to cave and karst management, a short set of questions was developed and distributed to federal land managing agency specialists to identify knowledge of cave and karst resources specific to each agency and unit (Appendix A). All protocols, restrictions, and application acceptance for investigations using human subjects relevant to the Code of Federal Regulations Title 45 – Public Welfare Department of Health and Human Services Part 46.102 were followed to satisfy requirements for both Western Kentucky University and the National Park Service. Informed consent was obtained from contacted managers about use of information and their rights. The questions are intended to identify what the managers feel are their primary threats and challenges as well as what they have employed and think should be considered with regards to appropriate management action. The questionnaire is exploratory in nature. Questions were designed to gather baseline data on existing knowledge of cave and karst resources and management on federally managed lands that possess solution caves and karst. The results were then used to identify and describe the nature of research and scientific knowledge related to identified and documented cave and karst resources, and to explore existing relationships and opportunities with outside agencies, entities and organizations in furthering the study and management of cave and karst resources on federally managed lands. Lastly, the questionnaire seeks information on reoccurring shortfalls within the protection and needs of cave and karst management from NPS and other federal managers. Questions address cave and karst management concerns found throughout the literature and observed within the federal land management agencies including GRSM.

The questionnaire was sent to federal land managers at units of the National Park Service (NPS), USDA Forest Service (USFS), Bureau of Land Management (BLM), US Fish and Wildlife Service (FWS), Department of Energy (DOE), Department of Defense (DoD), Tennessee Valley Authority (TVA) and the Army Corps of Engineers (COE). Contacts were chosen by researching units directly managing caves and karst. Additionally, regional and national contacts in Geology, Biology, and Recreation were contacted for federal land managing units and asked to disseminate known units who have these resources to locate units unrepresented in the literature.

Replies to the questionnaires were compiled into "best practices" for management guidance based on relevance and application to the management concerns specific to GRSM. Using GRSM as a case study, management concerns were evaluated based on the protection afforded by literature-supported, landscape-wide "karst management" or more traditional, agency driven "cave management" best practices. Examining recurring responses to the questionnaires will highlight common issues and solutions to federal, and more specific, NPS cave and karst needs. The incorporation of these findings into understanding the best approach at management is applied to GRSM resources and the development of guidance to protect the resource. This approach allows for an objective look at developing a cave and karst program supported by best practices specifically applicable to GRSM concerns. Known resources within GRSM are used to compare these management strategies, describing which afford the most logical protection of the resource. Crucial to the understanding of GRSM caves and karst, the study also seeks to create a centralized reference location for GRSM resource managers to access information surrounding GRSM caves and karst. A thorough assessment and compilation of historic and current research of biological, hydrological, geological as well as other components of GRSM cave and karst resources were completed and were then used to ultimately draft a Cave/Karst Management Plan specific to the needs of GRSM. Considerable effort was placed on verification and documentation of existing cave and karst resources in the literature as well as through extensive field visits to GRSM karst areas and caves.

Field Visits and Review

A first-hand understanding of the resource was obtained through numerous visits to karst areas and caves both in the park and along its borders to pull together an understanding of the processes and concerns surrounding their needs. Over thirty-five cave trips and hundreds of hours spent traversing GRSM karst areas over thirteen years of involvement in GRSM has given an in-depth interpretation and understanding of these resources. Photos and detailed notes were taken of the current state of the karst areas including the documentation of resource damages from overuse, illegal use, as well as pre-park use. All known karst areas and caves were visited multiple times, contributing to a clear understanding. Additional resources were documented as well as potential management concerns across the resource. Visits to caves and surficial karst resources validated previous surveys, biological species presence/abundance, and provided and understanding of future needs. Trips to visually delineate hydrological flow paths allowed for a basic understanding of the subterranean environment as a mechanism of pollution transport within the karst system and ultimately out of the park.

Consultation

Stakeholders outside of the NPS and GRSM were contacted to develop relations as well as collaboration on preliminary studies of the resources and management concerns. Members of the Tennessee Cave Survey (TCS) were vital to understanding the extent of cave development, condition, and exploration history as well as support for in-cave logistics. The incorporation of the Knoxville Volunteer Rescue Squad (KVERS) for support, logistics, and safety is vital to all operations within GRSM caves.

Chapter IV: Results

Questionnaire Findings

Combined Unit-level Data

In total, thirty-two federal land managing units responded to the unit-specific survey. Four of those replied with incomplete data or were unable to have a specialist reply. Units responding with usable information included five BLM, sixteen NPS, four USFS and three USFWS. Land managing units outside of those covered by the FCRPA did not respond to the questionnaire (DoD, DOE, COE, and TVA). The twenty-eight units reporting with usable information represent over 3400 caves on federal land. Of these caves, thirty-five percent were reported as open for public use with no restrictions for access, and forty-three percent were reported restricted for public use. Nine of the units reported unit-specific cave management plans had been implemented, and seven reported that unit-specific cave management plans were in process. Twelve units reported cave-specific management plans had been implemented. Six units reported cave-specific management plans were in process.

For all units reporting, forty-six percent reported an increase in permit requests for scientific study over the previous years, forty-six percent reported permit requests for scientific study remaining steady, and eight percent reported a decrease in permit requests for scientific study. Thirty-five percent of units reported permitting for recreation remaining steady; fifty-four percent reported an increase and eleven percent a decrease from previous years. Nineteen of the units reporting have a permitting process in place. Overall, law enforcement actions, described as activities punishable by law, for all units reporting appear to be on the rise. Fifty-four percent of units reported increasing enforcement actions. Twenty-nine percent reported decreasing enforcement actions, and fourteen percent reported enforcement actions to be remaining about the same.

For all units reporting, sixty-eight percent currently have active programs of research and scientific study of caves and karst areas. Respondents were asked to identify which types of research or scientific study had been completed or were currently underway in the unit. Sixty-eight percent reported survey and mapping, forty-three percent geological, fifty-seven percent hydrological, sixty-eight percent biological, fifty percent archaeological, forty-six percent paleontological and twenty-nine percent other. Respondents were asked to note “other” types of research, and responses included historic, interpretive, radon, microclimate, air/wind currents, effects of human impact and recreational use studies.

Seventy-five percent of units reporting indicated that cave and karst management practices in the unit were affected by research. Management actions were grouped into several categories, including access and enforcement measures, tour control measures, environmental and species control measures, research and education measures, and development of management guidance (Table 1).

Respondents were also asked to identify specific threats and challenges to cave and karst areas. Threats and challenges were grouped into several categories, including access, use and enforcement, environmental and species control, internal and external, and research and education (Table 2).

Seventy-one percent of units reporting indicated formal relationships with outside agencies, entities or organizations in regards to the scientific study of caves and karst

	Accessibility, Use and Enforcement	Control Tours	Environmental and Species	Management Guidance	Research and Education
Management Actions	closures -caves -roads -trails -sinks -areas in open caves; -seasonal closures (bat and non-bat related) install -gates -intrusion alarms -cameras limit recreation use of permitting restrict permitting levels use VIP (stewards) -trip leaders -education -relationship building -curb agency costs	use park staff -on all tours -flagged trails -trip leader limit group size upgrade trails -paved -lit trail use VIP -trip leader -training -trip reports	clean trash photo document remove graffiti/restoration clean sinkholes on private lands invasive species control -chytrid -White-nose Syndrome -microbes -lampenflora restricted surface use pesticide training collaboration -state -within agency -federal -specialists -universities	buffering for timber harvest/development -refrain from karst areas cave management team -unit wide -agency wide -region wide cave rescue plan -collaboration -internal presence development of standards and guidelines or management plans formal agreement to survey and inventory -collaborate with cavers -NSS, CRF karst coordinator to review all project proposals -specialists for karst manage all karst areas as if caves are present -holistic approach	signage -cave entrances -karst areas -geologic areas GPS/GIS -document resource -data base sharing ground searches for caves (ridge walk) -inventory resource -karst vulnerability inventory resources -biology -bats -speleothems survey/mapping -standardized -data share monitor climate water quality monitor visitor impacts monitor slope/failure dataloggers

Table 1. Successful management actions reported from federal agencies

	Accessibility, Use and Enforcement	**Environmental and Species**	**External**	**Internal**	**Research and Education**
Threats	ARPA violations resource damage geo-caching illegal entry inattentive cavers increasing visitation close to large population overuse rock climbing uncontrolled use vandalism graffiti trash	contaminants pollution global climate change mineral extraction timber harvest trampling invertebrates water quality White-nose Syndrome	adjacent development fluctuation of water levels (human controlled lake) illegal dumping non-compatible land use and pollution (ranching, runoff from farming) non-protection of watershed outside park boundaries road development vehicle accidents	balance use with protection buildings sewer in-holdings limited ability to enforce poor tour management	lack of education lack of baseline data -general information lack of karst-specific studies -holistic management lack of significant evaluations and protection -no karst focus no existing research program
Challenges	access vs. protection -priorities high visitation how to determine what should be publicly accessibly -vulnerability index how to implement permitting improper usage increasing requests for inventory/collection of rare species # and extent of caves political pressure to allow entry preventing non-permitted access	pollution -farming applicants White-nose Syndrome -collaboration with interest groups -access management -funding -personnel -additional responsibilities -unit interest/ and involvement	cave watersheds outside park boundaries -delineation -outreach activities outside park boundaries -outreach -assisted management fluctuation or water levels (human controlled lake) -define resource damage -mitigation plan	funding removal of structures over cave in-holdings access roads changing management priorities and philosophies no cave management program caves not a priority for agency -define needs staff availability and interest -use of VIPs rotating upper management	funding lack of knowledge about resources -disconnect with literature and specialists availability and interest of researchers -seek specialists educational opportunities -university and community involvment education (surface use impacts on caves and systems) -community outreach

Table 2. Treats and Challenges reported by cave and karst managers on federal lands

resources associated with the unit. Sixty-one percent of the units reported that these relationships were formally recognized (e.g., codified by a Memorandum of Understanding [MOU] or other agreement). Respondents identified several federal agencies (USGS, USF&WS, BLM, USFS, NPS, and NCKRI), international agencies (Ministry of Forestry, Canada), several state agencies (state natural resource agencies, state fish and game agencies, state cave survey/study), other organizations (the National Speleological Society [NSS], Cave Research Foundation [CRF], The Nature Conservancy [TNC], state speleological societies, the Ozark Underground Laboratory, private organizations, and local caving groups) and many Universities. In most cases (fifty-seven percent), the outside agency, entity or organization approached the unit, or worked cooperatively with the unit, with a request to conduct research.

NPS Unit-level Data

Sixteen NPS units reported with usable information. Units reporting, listed by their NPS designations, included ABLI (Abraham Lincoln Birthplace National Historical Park, KY), AMIS (Amistad National Recreational Area, TX), BUFF (Buffalo National River, AR), CAVE (Carlsbad Caverns National Park, NM), CHCH (Chickamauga and Chattanooga National Military Park, GA/TN), CUGA (Cumberland Gap National Historical Park, KY/TN/VA), GRBA (Great Basin National Park, NV), GRCA (Grand Canyon National Park, AZ), GRSM (Great Smoky Mountains National Park, TN/NC), GRTE (Grand Teton National Park, WY), NATR (Natchez Trace Parkway, MS), OZAR (Ozark National Scenic Riverways, MO), SEKI (Sequoia and Kings Canyon National Park, CA), TICA (Timpanogos Cave National Monument, UT), WICA (Wind Cave

National Park, SD) and WICR (Wilson's Creek National Battlefield, MO). Note that several major NPS units who manage caves and karst are not represented due to lack of response. Included in these are MACA (Mammoth Cave National Park, KY), ORCA (Oregon Cave National Monument, OR), and JECA (Jewel Cave National Monument, SD).

These units represent over 3.2 million acres containing 1625 caves. For these units, fifty-one percent (825) of caves were reported as open for public use, and forty-four percent (712) were reported restricted for public use. Open generally meant that access was not restricted based on reason for entry. This would include recreation.

Eight units reported that unit-specific cave management plans had been implemented, and seven reported unit-specific cave management plans in process. GRSM falls under "unit-specific plan in progress." Four units reported cave-specific management plans had been implemented, and four units reported cave-specific management plans in process.

A majority (eighty-one percent) of the sixteen units have a permitting process in place. Forty-four percent of units reported requests for scientific permits increasing, fifty percent remaining the same, and six percent decreasing. Twenty-five percent of units reported requests for recreational permits increasing, fifty-six percent remaining the same, and nineteen percent decreasing. GRSM has a crude permitting process for recreational caving, although the park has not authorized a permit in over ten years. Local cavers have stated that typically, GRSM management has not responded to recreational caving permit requests. Research permitting has been on the increase.

Overall, for the sixteen NPS units reporting, fifty percent of the units reported enforcement actions related to caves were increasing. Nineteen percent of the units reported enforcement actions staying the same, and thirty-one percent reported enforcement actions were decreasing. GRSM reports that law enforcement actions have remained the same but that law enforcement effort and presence surrounding caves and karst in specific, has declined.

Seventy-five percent of the units reported an active program of research and scientific study of caves and karst areas. Respondents were asked to identify which types of research or scientific study had been completed or were currently underway in the unit. Seventy-five percent reported survey and mapping, fifty percent geological, sixty-three percent hydrological, seventy-five percent biological, fifty percent archaeological, forty-four percent paleontological and thirty-eight percent other. Respondents were asked to note "other" types of research, and responses included historic, interpretive, radon, microclimate, air/wind currents, effects of human impact and recreational use studies. GRSM reports that they are very active in all areas of research and science across the park. The concentration focus is primarily biological with archeological being far behind in second. Primary interest has been towards the epigean, or surface biology of karst areas.

For the sixteen NPS units reporting, eighty-one percent indicated that cave and karst management practices were affected by research findings (Table 1). GRSM reports that most of their management is directed by research findings, followed by the guidelines and policy that support the science.

Respondents were also asked to identify specific threats and challenges to managing cave and karst areas. Threats and challenges were grouped into several categories, including access, use and enforcement, environmental and species control, internal and external, and research and education (Table 2). GRSM reports use and enforcement, as well as research and education, are the primary challenges to the resource.

Seventy-five percent of NPS units reporting identified relationships with outside agencies, entities or organizations in regards to the scientific study of caves and karst resources associated with the unit. Sixty-three percent of the units reported that these relationships were formally recognized (e.g., MOU). Respondents identified several federal agencies (USGS, USF&WS, BLM, USFS and NCKRI), several state agencies (state natural resource agencies, state fish and game agencies, state cave survey/study), other organizations (NSS, CRF, TNC, state speleological societies, Ozark Underground Laboratory) and many Universities. In most cases (forty-three percent), the outside agency, entity or organization approached the federal unit, or worked cooperatively with the unit with a request to conduct research. GRSM reports that University researchers and USGS researchers are the current primary cooperative relationships.

Agency-level data

Agency-level questionnaires were returned by the NPS's Cave and Karst Program Coordinator and USFS's Washington Office, Supervisory Geologist. In both cases the need and ability to collaborate and unify strategies across federal land managing units held responsible for fulfilling the FCRPA and fulfillment of their own agency guidelines were their primary concerns. Both identified the need to foster programs from within their own agency and to support unit level program development and collaboration. Both BLM and USFWS representatives on caves and karst were contacted verbally. Though the exact questions of the surveys could not be asked their feeling that collaboration from within their agency and across agency boundaries are the key to successful management and at the top of their priorities.

GRSM Karst Biological Data Compilation

Biological data

Through compilation of inventories and resurveys of cavernicoles (organisms who utilize caves for all or portions of their life cycle) and associated biota of the karst areas in the Great Smoky Mountains National Park, a total of eleven troglobitic (cave obligate species) organisms have been described in the caves of the park (Table 3). Of these eleven organisms, six have been identified to species, and five to genus. These organisms include amphipods, isopods, diplurans, millipedes, flatworms and arachnids. One of the eleven organisms (*Stygobromus fecundus*) is endemic to one cave (Gregorys Cave) in the park.

Approximately 270 organisms have been otherwise described in association with the caves and karst areas in GRSM. Of these, over 200 organisms have been identified to genus level, and fifty to family (Appendix B) (DLIA 2009). Over fifty of these organisms have been identified as troglophiles (species which can live their entire life below ground or above ground in the correct conditions), and forty as trogloxenes (species which must utilize caves for a portion of their life cycle). Many other more commonly occurring organisms live in both karstic and non-kartic epigean habitats non-specifically.

Species	Common name	Record location (cave)	Citation
Stygobromus fecundus	amphipod	GRC	Wallace 1984, 1989; Mays 2002
Stygobromus sp. (fecundus?)	amphipod	GRC	NPS 1991; NPS 1992; NPS 1993; NPS 1994; NPS 1995; NPS 1996; DLIA 2008
Stygobromus sparsus	amphipod	GRC, SGC, SPC, RMB, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002
Litocampa sp.	dipluran	BLC, CC1, RMB, SGC, SPC, WOB	Reeves 2000; DLIA 2007
Sphalloplana sp.	flatworm	GRC, RMB	Wallace 1984, 1989; NPS 1991; NPS 1992; Reeves 2000; DLIA 2008
Caecidotea incurva	isopod	GRC, MYC, RMB, WOB	Wallace 1984, 1989; NPS 1993; Reeves 2000; Mays 2002; DLIA 2007
Caecidotea sp.	isopod	MYC	Reeves 2000
Scoterpes sp.	millipede	BLC, CC1, GRC, RMB, RBC, SGC, SPC, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002; DLIA 2007
Appoleptoneta sp.	spider	RMB	Reeves 2000
Nesticus barrowsi	spider	CC1, CC2, GRC, RBC, RMB, SGC, SPC, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002; DLIA 2007
Oreonitides Beattyi	spider	BLC, CC1,	Paquin et al. 2009
Phanetta subterranea	spider	BLC, CC1, GRC, RMB, SGC	Reeves 2000; Mays 2002
Cave location codes: BLC= Bull Cave; CC1 and CC2= Calf Cave 1 and 2; GRC= Gregorys Cave; MYC= Myhr Cave; RMB= Rich Mountain Blowhole; RBC= Rainbow Falls Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; WOB= White Oak Blowhole			

Table 3. Identified and Described Troglobionts and Stygobionts of Great Smoky Mountains National Park

GRSM is one of the most biologically diverse ecosystems in the world (DLIA 2009). Scientists are just beginning to comprehend the number of species that inhabit the Smokies. It is observable that many of the epigean species that inhabit the karst areas in the park are widespread in non-karst areas as well; however, researchers have recently begun to inventory the species specifically associated with the habitats of cave and karst areas. Many species that thrive in karst habitats in the park are rare elsewhere within the park boundary (although they may not be considered rare outside of the park). However, it is interesting to note, for example, that two species of liverwort have been identified to live only in one of the karst areas in the park, and the closest "genetic relative" to one species is found in the Himalayas. A wide variety of terrestrial snails inhabit the karst areas in the park, and it is likely that once these species have been identified and described, there will be several new endemic species (DLIA 2009). The karst areas in the park exhibit significant diversity of epigean species, and further research may identify additional rare and endemic epigean species. In developing a comprehensive cave and karst management strategy, it is important to consider the management of epigean biology associated with the karst areas.

GRSM Field Interpretation and Additional Resources

(*see* Appendix C *for additional information on GRSM caves and karst resources*)

Cades Cove

Encompassing approximately thirteen square kilometers, Cades Cove is the largest fenster inside GRSM's boundaries. Figure 2 shows Cades Cove; the surficial karst and shallow karst represented on the surface by sinkholes is outlined in black. This area receives heavy visitation throughout the year, is extensively developed, and is the location of two known caves. The etymology of Cades Cove is unknown. The name "Cades," as a surname, shows no records for this area or this region of the U.S. (Shields 1981). From early records, references to a *cave* (Gregorys Cave) have led many to suggest that its initial name may have been "Cave Cove" instead of "Cade(s) Cove". It is likely a question that may never be answered.

Figure 2. Cades Cove -- Approximate exposed and shallow karst within fenster.

Cades Cove receives over two million visitors annually, who mainly come to travel the eleven mile paved loop road to experience the wildlife and 19^{th} century culture preserved in maintained fields and twenty-six historical structures. Cades Cove has been occupied by settlers from the 1700s to 1999 when the last lifetime lease expired. Early occupation of Cades Cove exploded in the 1830s and 40s due to road development. Also at this time the development of a post office (1833-1947) eased the burden of living in what was considered a remote area at the time. The height of settlement was around 1850 with 132 families and a population of almost 700 individuals (Dunn 2005).

Currently in Cades Cove the NPS manages, in conjunction with the twenty-six historic structures, a 159 site campground, eighty-one site picnic area, three site horse camp, six residential structures accommodating twenty-four seasonal (or transient) workers, a large maintenance facility, a horse concessionaire boarding facility and offices, visitor center, interpretation office building, and ranger station. In addition to structures, a several-acre settling pond has been incorporated into the main leach field operations near the entrance to the cove (western end), with an additional leach field adjacent to the visitor center in the eastern end of the loop road (back of the cove).

The karst hydrology in Cades Cove appears pretty straight forward on the macro scale. It is safe to assume, based on elevations of sinking streams and proximity to Abrams Creek, all of the precipitation that falls within the Cades Cove area finds its way into Abrams Creek's main channel and leaves the cove via that main drainage. Figure 2 shows Cades Cove as the low point in the area with Abrams Creek draining west; eventually out of the carbonate bedrock area. There could be unaccounted for ground water flow but the likelihood of long distant flow outside of the Abrams Creek drainage seems unlikely. Abrams Creek (historically referred to as Cades or Cove Creek) is the primary drainage of Cades Cove and is located on the floor and in the middle of the fenster. Abrams Creek is the largest "limestone" stream in the Smokies and one of the most biologically productive in the park (DLIA 2009). A much more complicated hydrology appears along the northern lowlands of the cove as well as along the floor of the cove proper. At the inflection point of the mountain, several streams draining Tater Ridge and Cave Ridge lose much of their normal flow to subterranean stream courses. In most, the loss of water begins to occur in the Cades Cove Metasandstone debris flows before entering limestone bedrock. Several streams have some sections of underground flow including Tater Branch, Feezell Branch and a main tributary to Feezell Branch, which flows along Hyatt Lane. In addition, Abrams Creek itself flows underground for a portion of its course in Cades Cove. It is lost directly into bedrock during periods of low flow and drought. The presence of intermittently water filled sinkholes throughout Cades Cove, both north and south of Abrams Creek, as well as under surficial non-carbonate debris flows, suggests additional karst flow in Cades Cove may exist in areas not easily discernable as karst topography.

Gregorys Cave

Gregorys Cave is located along the lower reaches of Cave Ridge on the northern slope of the Cades Cove fenster at an elevation of about 600 m. Named after the Gregory Family who lived near the cave until the time the park was developed, this cave was historically used as a food storage area to keep food cool in the summer and from freezing in the winter. Historically, a wooden gate prevented scavengers from entering the cave. At some point, this gate was replaced with a vertically slatted metal gate by the NPS.

Gregorys Cave has extensive references in pre-park files exemplifying its popularity in the Cades Cove Community. It was also one of two caves in Blount County (the other being outside the park-Tuckaleechee Caverns) labeled as a “fallout shelter” (GRSM *No Date*). In the back of this cave is a suspected petroglyph of a wild turkey thought to be the only visible evidence of prehistoric use of caves in the park by Native Americans (GRSM *No Date*). Park archeologists, through their observations, have suggested that evidence likely exist showing Native American use of the entrance area of this cave due to charcoal and stone fragments in sediment layers.

The cave has 305 m of surveyed passage with a vertical extent of sixteen meters. The cave is essentially a large paleo-trunk passage, with vaulted ceiling exhibiting heights from six to seventeen meters and widths almost twice that. There is also a low, wide side passage that extends over thirty meters (TCS 2011). The main passage is arguably the most decorated of any cave in GRSM (see Appendix b in attached Appendix C). Large ceiling to floor formations with large rimstone pools are highly developed from just inside the cave to the end, with the side passage being the exception. The west side of the cave exhibits solution pockets which continue to feed calcite saturated water to the white/cream formations, while inactive formations have retained their gray and black soot coloration from the historical use of fire in lighting the cave.

Gregorys Cave is biologically diverse, as mentioned earlier, being the type-locality of two obligate cave species (amphipods of the genus *Stygobromous*), one of which has been found nowhere else (Holsinger 1978). It has been a choice of scientists who wish to collect and study cave dwelling organisms of the Smokies due to its easy access and diverse cave fauna. The cave is also home to over 1000 bats in the winter, although until the NPS replaced the vertically-slatted gate with a bat-friendly horizontal gate in the 1990s, there was little recent evidence of bat use in the cave or the literature. There is no sign at the entrance of Gregorys Cave addressing entry restrictions, although there is a bat friendly gate, which prevents illegal entry.

Tory Shields Bluff Cave

Tory Shields Bluff Cave (also called Abrams Creek Cave in historical literature) is located within the Cades Cove karst window at an elevation of 536 meters. The opening is at the base of a large limestone outcrop in a dry floodplain/stream channel just east of an old quarry in the same outcrop. The cave is less than 10 meters from the north bank of Abrams Creek. The cave itself is mainly a horizontal crawlway with several small pools of water during wet periods. There are two entrances and a small skylight. The upper entrance can be connected to the lower but is physically restrictive to most people due to the small size. Historical use by an American black bear (*Ursus americanus*) and raccoons (*Procyon lotor*) has been mentioned in previous descriptions of this cave (GRSM 1989). The current map shows 129 meters of passage with six meters of vertical relief. It has been suggested that additional passage exists with obvious air movement but passage is too small for most to enter (TCS 2011).

Biologic components to this cave are poorly understood; several attempts have been made at exploration in hopes of duplicating the species diversity of nearby Gregorys Cave but the majority of the species are absent. This cave lacks the year-round epikarst drips that supply the necessary water for many of the aquatic cave species of Gregorys Cave. Additional work at varying times of year might be necessary to see if additional species use Tory Shields Bluff Cave as temporary habitat. Numerous Tri-colored bats (*Perimyotis subflavus*) are known to hibernate in this cave. There is no gate to prevent entry into Tory Shields Bluff Cave, although a nearly illegible sign alerts the visitor to the presence of an otherwise obscure cave entrance. The sign warns the visitor that a permit is required to enter the cave.

Rich Mountain

The Rich Mountain karst area is an approximately 0.37 square kilometer uvala (a large complex depression, or sinkhole, with subsequent smaller sinkholes within it). It is an extension of the greater Tuckaleechee Cove fenster, which is outside of the park. Known as Bull Sink, it measures approximately 610 x 610 m at its widest points on the south slope of Rich Mountain. Figure 3 shows this portion of the larger Tuchaleechee fenster, which is under GRSM management. The area within the sink and north out of the park (gray) are highly developed karst areas. The base of the sink drains into the Bull Cave System, one of six known caves with entrances in the sink. This area is easily accessible, and is the home to two of the deepest caves in the eastern United States. The epigean environment of Bull Sink is unique, containing an endemic species of liverwort with closest relatives being in the Himalayan Mountains (DLIA website 2008).

Rich Mountain Road, a one-way exit route out of Cades Cove dating back to the mid 1800s, exits the park after a short traverse of the sink. Historic use of the area is not well known. Records suggest that logging of the area left no trees standing and reports state that slash was dumped into the sink from both the road and the slopes of the sink. Additional accounts of the area after logging state that the cave was at time "inaccessible due to an entrance plugged with cut trees, mud, and water" (GRSM *No Date*).

Figure 3. Bull Sink, Rich Mtn. – Highly developed portion of Tuckaleechee fenster just inside of NPS (green) boundary.

Hydrology within the sink is unclear and several observations would suggest that the majority of flow paths find their way to a common resurgence in Short Creek in Dry Valley. Observations of flow within the three main caves on Rich Mountain (The Bull Cave System, Rick Mountain Blowhole, and privately owned Kelly Ridge Cave) suggest that Bull Cave provides the primary flow path of water through the mountain. It is likely that all the caves within Bull Sink are connected to some degree, but this has not been documented.

Bull Cave System (Historic Bull and Snakedance Entrances)

The Bull Cave System is the deepest known cave in GRSM (as well as Tennessee) at 282 m. It is ranked as the third deepest in the eastern US and the twentieth overall in the US. Bull Cave has two entrances, the historic entrance and the more recently discovered Snakedance entrance. The total mapped length of cave is 3656.4 m. It trends north and terminates outside of the park boundary at a low water sump (TCS 2011).

The historic entrance of Bull Cave is located in the drain of Bull Sink on the south side of Rich Mountain just within the boundary of GRSM at an elevation of 561 m. A short and well-worn trail leaves the parking lot at Rich Gap, traveling south west, down into the sink and to the entrance of Bull Cave. The sink and cave continually take water from a small surface stream that can be followed through most of the historical side of the cave. The historical descent into Bull Cave requires descending three vertical drops of twelve, fifty-two, and twenty-seven meters as well as some exposed down-climbs in often cold and wet conditions. The temperature of the water entering the cave strongly influences the temperature of the cave. At the historical terminus of the cave is a shallow dig which, when dry enough to allow travel, leads to the remainder of the stream passage and connection with the Snakedance side of the cave.

The Snakedance entrance is much higher than the historic entrance to the cave, on the south flank of Rich Mountain at an elevation of 634 m. The entrance is at the bottom of a steep-sided sink within the confines of the larger Bull Sink. This entrance is a vertical drop of thirteen meters followed by thirteen nearly continual drops ranging from three to forty-four meters to the Bull Cave stream passage and sump.

The historic side of Bull Cave is a hibernacula for the federally listed Indiana bat (*Myotis sodalis*) and is home to other cave species endemic to the park. The vertical extent of this cave system and possibilities for more discoveries in it and on Rich Mountain make it one of the most desirable caves for recreation and exploration cavers. There is currently no sign at either entrance (historic Bull Cave or Snakedance) warning against illegal entry. A once legible sign on the trail leading to Bull Cave has been recently stolen.

Rich Mountain Blowhole

Rich Mountain Blowhole [Cave] begins high along the south slope of Rich Mountain in a shallow sink at the head of a dry valley within the larger Bull Sink at 622 m. The entrance to the cave was illegally dug open and currently has a locked, air-restricting gate and entrance culvert to mimic pre-digging environmental conditions. This solid, ground-level, horizontal gate is often obscured by leaf litter, and there is no sign warning against illegal entry. The illegal alteration of material to gain access to this cave has been the center of much controversy between cavers seeking access to continue exploration of GRSM caves and NPS's hesitance to trust some cavers with these resources. Rich Mountain Blowhole is the second deepest cave in Tennessee (and GRSM) at 256 m. It rates nationally one place behind the Bull Cave System as the forth deepest for the eastern US and twenty-fifth across the U.S. Right or wrong, the discovery of this cave was and is paramount to understanding GRSM caves and karst and how to manage them.

Rich Mountain Blowhole continues to blow air out of nearby rock piles too small to enter; the dug entrance contains ten vertical drops that require rope to descend. It is similar to the Bull Cave System in that it follows a series of almost vertical bedding planes until it reaches at or near the water table where it begins a horizontal path north exiting the park. It also contains several domes which have been explored and added to the overall length of the cave.

Regardless of the air restrictive entrance gate, bats (Tri-colored bats) have been found to hibernate in this cave. Several species of cave organisms have also been found in this cave. Rich Mountain Blowhole, like the Bull Cave System, has extensive vertical extent and possibilities for more discoveries that make it another desirable cave to recreation and exploration cavers.

Calf Cave I

Calf Cave I is located just inside the GRSM boundary at Rich Gap on the periphery of Bull Sink at an elevation of 579 m. This cave and Calf Cave II are at the bottom of a small sink, six meters deep by eleven meters at its widest, along the trail to Bull Cave. Historically, a sign at the rim of this sink alerted visitors to the need for a permit to enter either cave. This sign has been stolen.

Calf Cave I is predominantly horizontal with a small stream passage trending towards the historic entrance to Bull Cave. This passage contains fifty-three meters of mapped passage with two rooms with high ceilings inside the entrance adding to the mapped eighteen meters of vertical extent (Matthews 1971).

Calf Cave II

Calf Cave II is at the bottom of the same sink as Calf Cave I. The cave is short at seventeen meters with well over the Tennessee Cave Surveys listed four meters of vertical relief. Just inside the entrance is a five meter vertical pit. The small stream passage trends in the same direction as Calf Cave I towards the historic entrance to Bull Cave (Matthews 1971).

Hidden Hole Cave

Hidden Hole Cave was first mapped in 1998 to a length of approximately thirty meters and a vertical extent of approximately nineteen meters, although the cave has been known for many years by Rich Mountain cavers. The cave is in a dry valley of the Bull Cave Sink at an elevation of 600 m. The entrance is a vertical collapse in unconsolidated limestone rubble requiring rope to enter. The remainder of the cave mimics the entrance and is a collapsing vertical shaft broken with debris plugs. The entrance is very dangerous, and it is difficult to avoid partial collapse during exploration. Due to the nature of its instability it is possible that at any time, additional passage will be revealed extending its length and depth and conceivably allowing additional access into either the Bull Cave System or Rich Mountain Blowhole (GRSM 1998).

Biology of this cave is unknown. Bats have been seen using it in summer months and one can conclude that winter use by bats, even if minimal, is probable. This cave is within sight of the Ace Gap Trail. There is currently no sign to warn visitors against illegal entry into this cave or its significant hazards.

Big Spring Cove

This area is typified by several sinkholes (< nine meters in diameter) in Metcalf Phyllite and Metasandstone debris flows that do not permit quick drainage of surface water into the underlying Jonesboro limestone. During wet periods, these sinks hold water and are important ecologically to such organisms as amphibians. The existence of sinks show that karst in this area is active but remains covered by weather resistant non-carbonate rocks of the Ocoee Supergroup. Figure 4 shows the flattening of the area

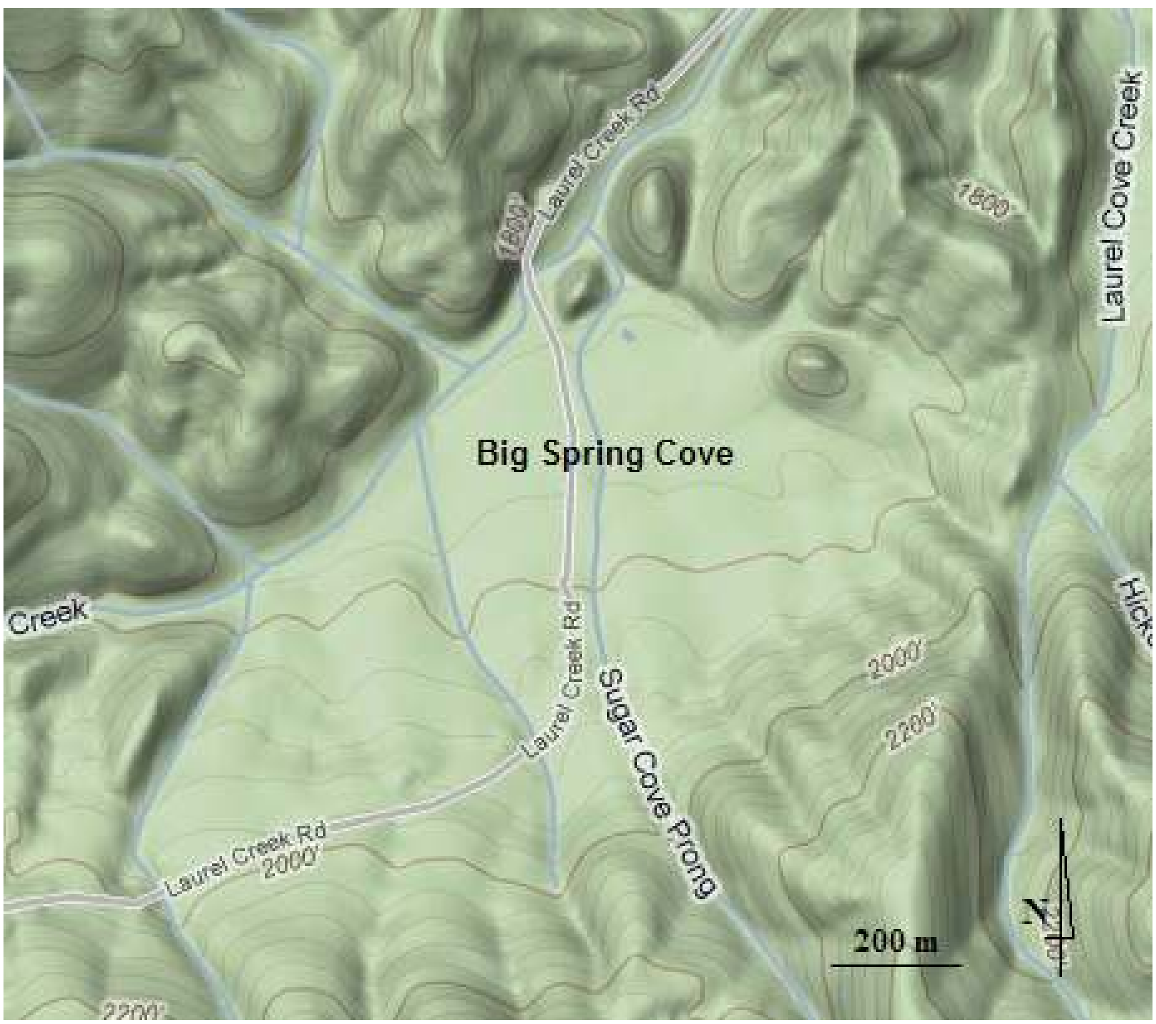

Figure 4. Big Spring Cove. – Example of early fenster development. No surficial carbonate rock.

typified by fenster development. This overburden causes a slow recharge of the karst hydrology. Geographic observation based on the leveling of topography suggests that this active karst area is approximately 0.56 square kilometers. Karst drainage is likely into the neighboring Laurel Creek/Little River drainage, but this has not been verified. Historic use of Big Spring Cove is evident in the altered topography of the cove. One of the sinks has been breached manually to drain water, possibly for farming.

White Oak Sink

The White Oak Sink karst area is also on the periphery of the Tuckaleechee Cove fenster and encompasses about twelve square kilometers. White Oak Sink is a very large uvala whose karst is continuous with that of the Tuckaleechee Cove fenster but is isolated somewhat by the elevation differences. Figure 5 shows uvala development in relation to surrounding non-carbonate bedrock (north, south, and east of the uvala) as well as continuity with the larger Tuckaleechee fenster to the west. The NPS does not maintain trails into or within White Oak Sink but an elaborate set of man-ways (unmaintained social trails) lead to many of the “desirable” features of the sink including caves, a cemetery, various wildflower ecotones, and historic home-sites. White Oak Sink is likely the most popular off-trail hike in the Smokies; the wildflower diversity has caused visitation in the spring to reach unmanageable parking congestion at the main trailhead and year-round use has continued to increase compared to other park locations. Resource degradation of surface ecology during peak visitation is obvious in the form of worn paths to certain wildflower communities, trampled vegetation, and litter.

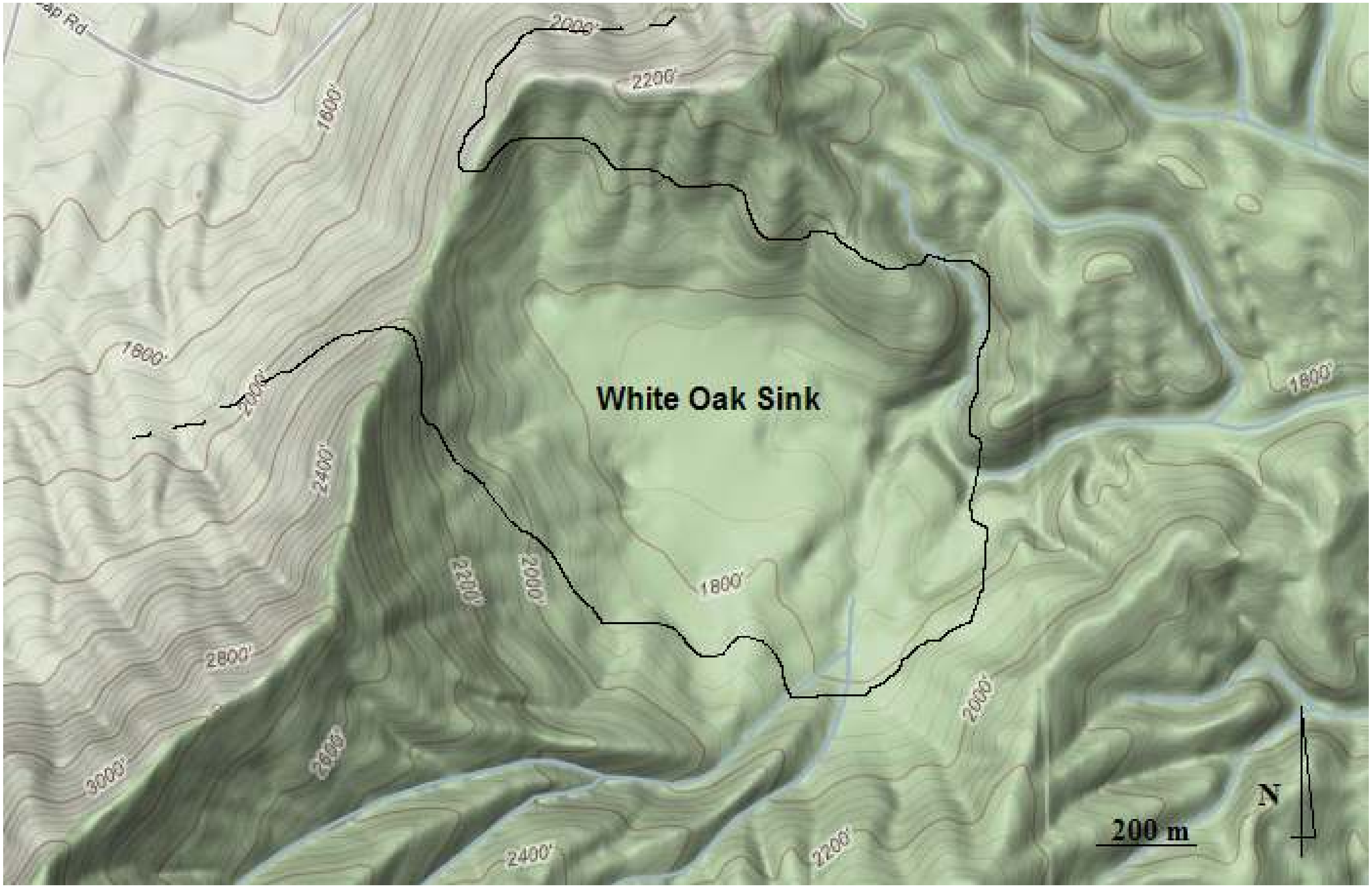

Figure 5. White Oak Sink. -- Highly developed portion of Tuckaleechee fenster just inside of NPS (green) boundary.

Current access to the sink is primarily by two locations. School House Gap trailhead, on Laurel Creek Road, allows access to School House Gap Trail and ultimately the main (southern) man-way accessing White Oak Sink. This route is approximately four kilometers one way to the bottom of the sink with half that distance on unmaintained trails. The lesser used trail into the sink follows the historic route into White Oak Sink and beyond to Cades Cove. School House Gap trail was the former road into Cades Cove around 1850. It was known as the McCampbell-Anderson Turnpike or road (Shields 1981). This road began in Dry Valley, a portion of Tuckaleechee Cove, and entered what would become GRSM at School House Gap. This road continued to what is now Laurel Creek road and via Crib Gap, enters Cades Cove. At School House Gap, the historic route into White Oak Sink veered west along a low-gradient stream, then through a shallow gap into White Oak Sink. At this shallow gap, the old access route leaves the metamorphic walls of the sink and enters the karst topography of White Oak Sink. Shortly below the gap at a junction with a larger dry valley the road passes (White Oak)Saltpeter Cave before reaching the bottom of the sink. Today, access to School House Gap and the park boundary require hiking more than a half mile on private property before reaching this man-way. At the gap this route is overgrown, but easily followed and allows for an alternate route into the area.

Historic land use was similar to Cades Cove; small-scale farming and limited livestock grazing in the bottom of the sink were the primary land uses of four families who resided there. After incorporation into GRSM, White Oak Sink was allowed to succeed into the closed canopy, secondary forest of today (Jenkins et al. 2007).

Recently, the NPS has installed a horse barrier at the entrance to the man-way from the School House Gap trail. In addition, "No Horses" signs were installed at both man-way entrances, and a sign at the edge of the main sink area suggests hikers stay on trails to reduce impact to the sensitive area.

White Oak Sink Hydrology

The hydrology of White Oak Sink can be pieced together by examining the known cave maps and recent survey of caves as well as understanding the geology and geomorphology of the sink itself. It appears that most if not all of the water that enters White Oak Sink is leaving the park through the sump at the bottom of White Oak Blowhole Cave (WOBH). A few solid observations can be made to support this. The largest surface stream entering the White Oak Sink sinks underground once it enters Rainbow Cave. It appears, by looking at elevations and geomorphology of the sink that from Rainbow Cave this water travels towards WOBH where it possibly resurfaces within that cave near the back towards the sump. An additional surface stream enters the karst system at Sinking Stream Cave where it travels through tight subsurface conduits past Pie Hole Cave. This stream appears to resurface in White Oak Blowhole from a high passage along the Northwest Passage before flowing into the breakdown and ultimately reaching the sump at the back of the cave. Few other surface streams show significant drainage that likely doesn't connect with these major conduits on their way to the sump at the back of WOBH. One exception might be water in Scott Gap Cave which appears to travel a different pathway out of the park or possibly connects beyond the known extent of WOBH. Dye tracing of White Oak Sink is needed to understand this complex system

White Oak Blowhole Cave

White Oak Blowhole Cave is located in the northeastern "corner" of White Oak Sink at an elevation of 500 meters. The entrance is obvious due to the large bat-friendly gate which protrudes like a box in front of a steep limestone bluff (see Appendix b in attached Appendix C). Behind the gate is a short climb down into the entrance room. In the floor of the entrance room is a triangular shaped opening which descends vertically just over nine meters into an elevated alcove of a much larger room. This room is estimated to be twenty-three meters wide by ninety-two meters long and nine meters high. The floor is scattered with large breakdown rocks from the ceiling. Two large leaching areas are observable from past efforts of guano mining and saltpeter extraction. The cave has a surveyed vertical extent of 134 meters and a length of 210 meters (TCS 2011).

The main extent of the cave is this large main room which trends downslope towards a terminal sump which has been dove to twenty-five meters. The water in this sump is beautifully blue and at times has many contrasting orange spring salamanders and red black-chinned red salamanders. A northwest passage continues for 121 meters feet from the entrance drop to a well-decorated room known as the "torch stick room". This portion of the cave is one of the primary roosts for Indiana bats and has seen extensive mining of guano for saltpeter extraction. The name "torch stick room" is given due to the extensive cedar torch stick fragments left behind by miners. Tally marks are also evident in the torch stick room as well as other portions of the cave as evidence of the mining that has taken place.

This cave is Tennessee's largest known Indiana bat hibernaculum with counts numbering close to nine thousand at their peak. Three additional species of bats are also common in the cave during winter months and together could account for close to 12,000 bats at their peak (GRSM *No Date*). Additional cave biota are species typical for GRSM caves but they can be difficult to find due to the expansive nature of the main room and complex breakdown in this cave. Although an interpretive sign exists on the gate explaining the importance of protecting bat hibernacula sites, the NPS sign directing visitors to obtain a permit for entry to the cave has been dropped down the entrance pit beyond the gate, and now rests in the main entry room of the cave. It is important to note that WNS was documented "PCR Positive" for a Little Brown bat (*Myotis lucifugus*) in 2010. This lists Blount Co. TN as one of the southern most location where the DNA sequence for the fungus associated with WNS, *Geomyces destructans*, has been located. The USFWS designates this county as "Suspected Positive for WNS" due to a lacking histology confirmation of WNS.

Rainbow Cave

Rainbow Cave, sometimes called Rainbow Falls Cave, is located on the southeastern corner of White Oak Sink at an elevation of 510 meters. The entrance to the cave is at the base of a waterfall, which drops nine meters after reaching soluble limestone at the Great Smokies Fault (see Appendix b in attached Appendix C). The Great Smokies Fault is clearly observable at the contact between the lower limestone beds and the upper weather resistant metamorphic rock of the Ocoee Supergroup. The waterfall and cave location are common stopping points for hikers in White Oak Sink.

There are at least two entrances into the cave at the base of the falls. One is a climbable pit, which corkscrews for three meters before entering a room under the breakdown pile below the falls. In this room, water from the falls percolates through overburden making it impossible to stay dry. Following the flow of the water, visitors enter a tight wet crawl that, depending on water level, may not be safely passable. Beyond this constriction is a small dome room with a side passage entering from the other entrance and a hands-and-knees crawlway in which the water follows. The second entrance is tight at the base of the falls, often choked with debris, but opens to follow an overflow channel of washed dolostone with calcite stringers (narrow vein of calcite mineral traversing the parent dolostone) for forty-six meters to a four meter high climb down to meet the other entrance route.

The hands-and-knees crawlway that follows continues for thirty-seven meters to the first nine meter drop. The drop is affixed with a bolted hanger (a mechanical attachment point permanently attached to the bedrock) and can be backed up off natural anchors such as heavy bedrock points upstream. The descent is wet and at the bottom, after a short nine meters of passage is another nine meter drop, bolted again in unabated water. Both bolts were placed by the Knoxville Volunteer Emergency Rescue Squad (KVERS) in February 2008 during the rescue of four young adults who became trapped and hypothermic during a late night, unpermitted trip into the cave. The terminal siphon is in a short down climb in the main room at the bottom of the cave. The room is spacious, ranging larger than nine meters wide by over one hundred feet long. From the siphon the room continues up over breakdown into a lofted area with one possible high passage lead.

This cave has the potential to be very dangerous during periods of rain. Flash flooding could easily trap people inside the cave as well as make either of the two water fall climbs very difficult. Species diversity is similar to other caves in GRSM. Current surveys show that winter bat use is high with numbers close to 100 individuals. Indiana bats hibernate here. There is currently no sign warning visitors against illegal entry to this cave.

White Oak Saltpeter Cave

White Oak Saltpeter Cave is located at an elevation of 550 meters in a small sink, eight meters in diameter, upslope of the bottom of White Oak Sink in an unnamed dry drainage in the direction of School House Gap. It is adjacent to the historic trail (road) that accesses White Oak Sink from School House Gap. The cave is very visible to hikers who follow the social trails that have developed along the historic route into the sink.

The name of the cave is a misnomer; there is no evidence that any saltpeter mining has occurred in this cave. It is unlikely that there was a reason to mine this cave. The cave is small and does not possess guano piles sufficient for extraction. It is likely that the neighboring cave, White Oak Blowhole, was called "Saltpeter Cave" at one time due to its extensive sign of nitrate removal efforts. The use of "Saltpeter Cave" was a common name miners gave to caves that were utilized for nitrate extraction. Some confusion in nomenclature can be speculated which has caused the name to be associated with this nearby cave instead of the other likely choice.

This cave is relatively small compared to the neighboring White Oak Blowhole and Rainbow Cave. It has fifty meters of surveyed passage with a vertical extent of six meters. The cave has a large entrance room with two small domes on its north margin. It receives water from a small fissure which quickly disappears into a hole in the floor which could possibly be explored by a very small person. The main room funnels into a small crawlway with water draining from the back of the cave. This water disappears through a tight constriction in the floor which immediately opens into what looks like a possible lead. Inspection of both cave maps suggests that this water likely emerges along the eastern wall of the main room in White Oak Blowhole Cave.

Beyond the drain in the floor, the cave opens back up into a series of short upper passage sections connected to the small stream passage before the source of the stream is reached at a spring-like area in the back of the cave. There are two very small leads off the south east side of the cave but both are too tight for most to enter. At least one of these exhibits significant air movement suggesting additional passage or more likely connection to White Oak Blowhole Cave.

This cave receives a fair amount of illegal visitation which has resulted in several names/initials written in mud along the far reaches of the cave. Most of the dates are within the past fifteen years with several new additions identified with each visit. A barely legible sign is propped up against the entrance to the cave, warning visitors against illegal entry (see Appendix b in attached Appendix C). Several hundred bats (primarily Tri-colored bats) use this cave in the winter as a hibernacula. Indiana bats, Little Brown bats, Big Brown bats, and Tri-colored bats have all been seen in the cave during winter months and Tri-colored bats roost there during the day in the summer.

Scott Gap Cave

Scott Gap Cave is in a large sink in the northwest portion of White Oak Sink at an elevation of 555 meters. The entrance to the cave is under a large exposed portion of Jonesboro limestone at the base of the sink, which on occasion fills with organic debris. Directly inside the opening is a vertical entrance drop of eleven meters into the cave. A tilting passage approximately eight meters high by an equal distance wide precedes downslope following the dip of the beds. A much smaller passage runs upslope for a short distance before terminating at a four meter dome. The majority of the cave down slope is a series of easy climb-downs to a constriction at the second drop of twelve meters. At the bottom of this drop, a small tight stream passage drains north out of the small room with an eleven meter ceiling. The low stream passage winds north for thirty meters before it becomes too tight to proceed.

This cave has housed 200 or more Indiana bats during the winter, though recent counts have been much lower. Other bat species hibernate there as well including the Little Brown bat, Northern Long-eared bat, and the Tri-colored bat. In addition, the small pool of water in the bottom of the second drop contains many of the aquatic cave organisms found in other GRSM caves with pooled water. A sign at the rim of the sinkhole warns visitors against illegal entry and the need for a permit to enter the cave (see Appendix b in attached Appendix C).

Foothills Parkway System

(Walland, Wear Cove, Cosby, and Pigeon River Karst Areas)

GRSM manages a narrow strip of land around the Tennessee side of the park designated as the Foothills Parkway System. Not all of the parkway is complete at this time. The geology of the parkway is consistent with the main portion of the Smokies with older metamorphic rock at higher elevations and younger carbonates beneath. This corridor crosses several large fensters; two caves are known from this right of way, one in the Walland fenster (Shady dolomite) and one in the Wears Cove fenster (Jonesboro limestone). Karst along the Foothills Parkway System is minimal, occurring often at parkway junctions at lower elevations. Common features are large sinkholes and limestone bluffs. Actual size of karst areas of the parkway is unknown.

Stupkas (Myhr) Cave

This cave is named both Stupkas (GRSM's first naturalist) and Myhr (adjacent landowner) in literature but exists as Stupkas Cave in the Tennessee Cave Survey (TCS) records. Stupkas Cave is 213 meters long with fifteen meters of vertical extent. The cave is mainly a tight, wet, and winding stream channel. The entrance is a collapse adjacent to the resurgence spring. The spring is on adjacent property and feeds a large pond owned by the Myhrs and is also their main source of water.

The cave is developed at the base of the south slope of the Wear Cove karst window at an elevation of 466 meters. Development above this cave and the Foothills Parkway System is thought to be the source of seasonal turbidity of the Myhr's water source in the past ten years. Cave biota in this cave is similar to other GRSM caves but also possesses the type-location of an endemic spider (troglophile) of the genus *Nesticus* indicating the importance of protection. According to bat surveys, bat diversity in this cave seems to be high, although records indicate population numbers of many species are relatively low. There is currently no visible sign warning against illegal entry.

Newly Recognized Karst Areas and Their Resources

Through extensive field investigations as part of this research, a better understanding of GRSM karst and cave resources was obtained. In addition to the five primary karst areas managed by GRSM, the location of 4 additional karst areas were documented through additional conversations with park personnel, local geologists, and field observations. Many of these areas are small pieces of much larger karst areas not managed by GRSM.

Foothills Parkway-Walland

At the eastern terminus of the Foothills Parkway West, the park manages a small section of the parkway which crosses exposed carbonate rock along Little River. The area is not well marked and actual size is unclear. This area represents a portion of the Walland fenster, a large area containing several caves in Shady Dolomite. Where the river cuts through the carbonate bedrock, steep cliffs remain. The higher flat topography of the area consists of large shallow sinks which obviously drain into the nearby Little River or adjacent ground water. No visible flow of water has been documented in this area outside of the neighboring Little River. One new cave was observed on GRSM managed land. This is the only known cave under GRSM management in the Walland fenster-Foothills Parkway Cave at Walland.

The Foothills Parkway Cave at Walland has developed in a fissure in the Shady dolomite of the Knox Group at an elevation of 300 meters. It is on a limestone bluff high above Little River on a narrow strip of the Foothills Parkway System. The vertical extent is enough to warrant the use of a rope to access.

The cave is a vertical fissure of approximately six meters deep with less than four meters of traversable passage at the bottom. It does show signs of dissolution of calcium carbonate within the cave and Tri-colored bats are known to hibernate under several small shelves along the bottom of this cave. The common Cave Salamander (*Eurycea lucifiga*) has been seen in this cave. No biological inventory has been done outside of the author's observations.

Foothills Parkway-Interstate 40

In the far Northeastern corner of the park, along part of the Foothills Parkway East, is a low lying karst area adjacent to the Little Pigeon River in Cocke Co., TN. The area needs further delineation as to its exact size but field observations show karstification taking place on both sides of Interstate 40 at the junction of the Foothills Parkway East's eastern terminal. The area furthest east adjoins the Little Pigeon River where limestone is very obvious along the river incision and flood plane. No cave development is observable though dissolution of limestone is apparent along rock outcrops. It appears that the karst area continues under I 40 to the western portion of the terminus of the Foothills Parkway East. At this location, it appears that the carbonate rocks are covered with non-carbonates. No limestone was found. Active karst is seen as large shallow sinks on what looks to be an old river terrace higher up on the mountain flanks.

Little information exists in park literature on the area. General geology of the karst bedrock appears to be consistent with other park carbonates. Cambrian- Ordovician limestone (Jonesboro Limestone) would be the predominant karstified rock. Further interpretation of the rock itself might yield more detail to its origin or similarities to Blount or Sevier Co. limestones. No subterranean hydrology has been observed in this area outside of the Little Pigeon River.

Foothills Parkway-Cosby

Little is known about the karst areas around the junction of the foothills parkway and US route 321 (SR 32, 73). Aerial photos, topographic maps, and park boundary maps suggest that some karst is managed by GRSM in that area. The expansion of kudzu on adjacent lands makes any comparison impossible. The lack of park boundary signs as well as private property make attempts at defining the boundary somewhat difficult. At a minimum, karst is present at the lowest areas along Cosby Creek. Reputable reports from cave explorers and naturalists indicate that carbonate bedrock exists higher up on the flanks of Webb Mountain but access is difficult and location have not been documented. Topography in that area does not suggest that those areas contain karst or if they do fall under management of GRSM. The only observed hydrology is the surficial Cosby Creek, the main drainage of the valley in this area.

Calderwood Karst area

Newly acquired NPS lands along the eastern banks of the Little Tennessee River have revealed some karst topography. The land is adjacent to property owned and maintained by Topoco, a subsidiary of Aluminum Company of America (Alcoa), as the Calderwood Hydroelectric Development Area. The Calderwood property has several documented caves and active karst hydrology (TCS 2011). The area to be managed by GRSM is still being surveyed to determine how much of the acquired property will contain karst or caves. At this point field interpretation seems to suggest that the area known as “The Bulge” has the best possibilities as some of its south and western perimeter will adjoin known karst areas in the Calderwood karst window. However, Topoco’s choice to keep the lower, flat topography of the area will omit much of the highly karstified bedrock.

The area known as the “Chocolate Bar” does not appear to possess any karst landscapes but park biologists have explained that the bedrock is high in calcite, suggesting a similar biology to epigean karst areas. Hydrology in the Chocolate Bar would likely not be karst in nature. However, caves on Topoco's property adjacent to The Bulge suggest at least some subterranean flow which has possible origins higher up slope in GRSM managed land. Field observations do not show any distinct subterranean input of water into the non carbonate areas within GRSM's management area.

Newly Recognized Caves and Their Resources

In addition to The Foothills Parkway Cave at Walland, three additional solution caves have been identified in GRSM. All three additional caves have been located in the greater White Oak Sink area of the park.

Scott Mountain Cave

Scott Mountain Cave is a very short solution feature high on Scott Mountain at an elevation of 680 meters. It is within the confinement of White Oak Sink on its northwestern slope, and the entrance is a small inconspicuous hole that becomes covered with leaf litter every fall. The cave is short, about nine meters, with a sloping portion just inside the entrance suggesting active subsidence. The ceiling is low and only the entrance area permits standing. The back of the cave doesn't seem to warrant further attention. There does seem to be hydrological flow during periods of rain draining the back of the cave, ultimately flowing into the loose debris at the bottom of the sink at the entrance.

Interestingly, the cave always seems to contain fresh Allegheny Woodrat (*Neotoma magister*) nesting material (fresh vegetation and leaf litter) as well as a very large population of the spider *Meta ovalis*. This species usually numbers in the twenty to fifty range within sight of the entrance. The Cave Salamander has been seen in this cave on numerous visits. No biological inventory has been done outside of the author's observations. No sign exists that warns visitors against illegal entry, or the presence of a cave. Little indication of human activity suggests entry is not taking place at a level high enough to warrant concern.

Sinking Stream Cave

Sinking Stream Cave is another small cave within White Oak Sink. Its opening is at the bottom of a deep sinkhole at the foot of a small stream at an elevation of 555 meters. The sinkhole is collapsing, and trees are occasionally uprooted along its rim and sediment is continually drawn into the entrance to the cave. The stream disappears prior to the sinkhole except during periods of extensive rain. The cave is unmapped and on occasion seems to blow a slight amount of air. It is highly possible that it is connected to White Oak Blowhole, likely hydrologically.

The cave entrance is muddy and occasionally plugged, which leads three meters to a short climb down of seven meters. Water enters through breakdown into the small pit and quickly disappears into the coarse gravel floor medium. Old pottery fragments and man-made materials from pre-park homesteading were found within the cave pit suggesting the sinkhole has been used as a trash dump previously. This suggests further surveys to determine archeological significance. No biological inventory has been done outside of the author’s observations. There is currently no sign warning visitors against illegal entry, or alerting visitors to the presence of a cave. Some human activity has been observed at the entrance.

Pie Hole Cave

Pie Hole Cave is located less than 90 meters from Sinking Stream Cave on the western slope of White Oak Sink at an elevation of 550 meters. The cave is inconspicuous except for the large sinkhole it is in. It appears that the sinkhole has been used as a repository for field rock during homesteading as one side of the sink is awkwardly man made with loose chunks of limestone-possibly of rock removed from fields prior to farming. The cave is hidden among tall vegetation during summer months but visible during winter. The cave itself is small, less than ten meters in length. It corkscrews down into a muddy, rocky sink with large bedrock along one wall. Between two large pieces of limestone is a fissure with substantial air and a faint gurgle of water. This is likely the water from Sinking Stream Cave. It seems possible if not likely that this water continues towards White Oak Blowhole Cave and resurfaces along the northwest passage of that cave where a high lead discharges a slightly larger amount of water.

Pie Hole Cave gets its name from the shape of the opening which looks like a mouth. Also notable is the use of this cave by bats at several times of the year. No biological inventory has been done outside of the author's observations. No sign exists that warns against illegal entry to this cave, or alerting visitors to its presence. Little or no human sign has been observed in or near the cave.

Chapter V: Discussion and Conclusion

Karst (Landscape) vs. Cave (Specific) Focused Management

In applying best practices to the development of a GRSM specific cave and karst management plan, there are two potential perspectives as mentioned above: a cave focus and a karst system focus. The first idea is that a focus on the cave, as the main managmenet entity, is the primary need of land managing units and in some cases incorporated into that is the protection of the karst areas surrounding it. The need to protect and manage caves is obvious. Federal policy has elevated this need and directs much of the focus to the direct anthropogenic affects on caves, such as deterioration due to uncontrolled visitation. A focus on caves as a primary management need can provide a solid framework for the protection of a park unit's caves and karst areas known to be continuous with the cave. Unfortunately, the lack of focus this directs at karst as a whole can lead to an omission of karst resources that do not posses significant caves as well as karst processes which are often left out of management due to a misunderstanding of karst landscape complexities. The cave-focused approach is negatively magnified by units that are reactively managing these resources (caves and karst features) due to lacking policy suggesting a focus on karst. Within the literature of the academic structure we have seen a holistic focus on karst systems, the cave being but one component of that system that needs considered in the protection and management of the landscape. Active karst topography develops in GRSM when rainfall picks up carbon dioxide from the atmosphere and enters the karst environment as a weak carbonic acid. The reaction carbonic acid has on carbonate rock is what further develops geologic fractures and fissures in GRSM limestones into rapid transport subterranean conduits and aquifers. Ultimately these processes aid in the larger development of these spaces into caves.

Caves are arguably the most recognizable and studied component of karst systems. Humans' interest and understanding of caves has been the root cause of why we seek to enter that environment. Caves have been accessed across the planet during prehistoric, historical, and in modern times. Even when utilized as spiritual places, they have seen permanent alteration and damage due to visitation. Further degradation of cave resources followed resource extraction such as saltpeter mining. In more recent times in the USA, caves have been the source of considerable exploration. Often competitively, caves were explored to depths and lengths at rigorous paces, sometimes without regards to cave ownership. In all cases, human visitation has directly negatively impacted cave environments. GRSM caves have seen similar histories resulting in irreversible effects to resources. The value we have placed on caves has shaped our need to protect them and restrict the effects we impose when we enter these environments. The management of caves derives from the understanding of the resource and the need to prevent direct negative impact to the resources of the cave, not limited to any or all-definable resources. The protection of the cave is synonymous with protection of its resources. Resources such as the hydraulic component of solution caves have shaped and defined their physical properties as well as supply habitat for aquatic ecotones. To protect the hydrological resources in caves, the hydrology of the karst system must be defined and protected as well.

The word "cave" elicits a variety of reactions from land managers depending on their experiences, resources, knowledge, and interests. For those without a strong interest in caves, they can be a frustrating resource with complex scientific processes and often social, cultural, and political complexities over access. When forced to consider the management of caves, what is "unknown" to the reactive manager leads to a lack of protection. On the other hand, those managers with a strong interest in caves find that the significance of "cave" often stretches beyond the confines of their job into lifelong relationships and collaborations with cave scientists, management specialists, and the general caving public. Resource management of caves, especially on federal lands, is done by a small group of managers. The "unknown" to these managers, with regards to caves, is the primary factor that drives them. The dynamic nature of caves, especially the possibilities of new scientific discoveries and management challenges, draws their focus to advance the science of management, collaboration, and to provide protection. In addition, these managers have pushed the policy and guidelines along with the current literature to their fullest potential to provide specialized protection of caves and karst in their management units. The social complexities of caves, particularly cave access, are why we see so much legislation directed at their management. Policies such as the FCRPA and agency specific guidance are necessary and clearly direct the needed attention to support management with regards to accessing caves. The specific management of caves is clearly supported in literature and policy but can fall short in its ability to support proactive management of the greater karst environment.

The focus on landscape-wide land management is nothing new to the National Parks Service or other federal land managing agencies. The idea and focus on the interconnected relationships at the landscape scale has seen considerable application as anthropogenic challenges become more complex to the manager. In developing best practices for resource management, an understanding of the inherent thresholds these resources have with regards to human impact, both directly and indirectly, is important to adaptive management. Caves have received a substantial amount of attention in support of the need to focus on their protection. The understanding and management of caves is extremely important to federal land managers bound by the FCRPA. In areas where there are no known caves, but the potential exists (such as developed karst topography), the policy and guidelines which place a need to protect karst in light of caves does not place significant protection on the karst resources themselves, apart from caves. In a karst landscape the management of unknown caves, hydrology, potential karst development (cave development), and connected biological micro-habitats all must be considered significant regardless of proximity to significant caves. In addition, karst subsurface flow paths can provide long distance transport mechanisms for pollution supporting a need to consider alternative management for surface activities on karst. Without a holistic view of karst at a landscape level, cave management only provides resource protection in light of known caves and their associated karst.

NPS Management

Caves on NPS and other federal lands are being utilized at increasingly higher rates every year based on managers' responses to questionnaires. Use by scientists, researchers, and recreational cavers is on the rise in most land managing units and overall shows a trend that will likely continue as scientific inquisition continues and human population expands. In conjunction, these units also show an increasing number of violations with regard to activities such as illegal access and cave vandalism. This is to be expected as use and popularity increases. The trends and activities seen across the nation on federal lands have also been reported by GRSM and are important things to consider. As these trends continue, so does the need to better protect these resources. Most successful units who protect caves and karst do so with strong support from outside interests such as affiliates of the National Speleological Society as well as universities and other agencies. This approach has fostered formal agreements as seen through the numerous MOUs surrounding cave and karst resources. GRSM does not have any formal agreements specific to their resources but are incorporated into several NPS MOUs with groups such as the NSS, Bat Conservation International, The Nature Conservancy, and other federal agencies.

Congruent within all NPS units with a proactive cave (and karst) management program is the understanding that policy and guidelines on cave management require the management of adjacent karst landscapes to be productive. NPS units such as CAVE, CUGA, GRCA, SEKI, and WICA have successfully developed holistic programs concentrating on caves and their associated karst environments. Their management plans clearly address management beyond the focus of the caves themselves and the resources found within them. The success of these programs follows the clear text in the FCRPA, MP2006, and RM#77. Furthermore, these park units provide specific guidance within their plans and guidelines stating that protection of a given cave is afforded through protection of the complete karst system within which the cave exists. Though the term *cave* suggests a primary focus on caves, in these successful programs, karst protection is implied and carried out. The success of a cave and/or karst program in a NPS unit undoubtedly requires complete support from within the NPS unit and from the individual or team directly responsible for its success.

NPS units which did not apply direct management to cave resources often lacked any cave management program, cave specialist, or cave specific management team. These units, through their own observations of specific cave and karst management needs, often did not afford protection to the karst environment outside of normal operations. There appears to be a dichotomy in these units between and understanding of caves and karst management rather than a thorough understanding of the science and policy suggesting management of karst is necessary in the protection of caves (and vise-versa). It further suggests that as the focus on cave, and to a lesser degree karst resources are taken out of priority management, the focus and management of caves becomes myopic. Without strong policy to force attention at karst, successful programs seem to be driven by one or more proactive managers who passionately seek to protect these resources.

Another management concern of units who operate without a formal cave/karst program is the “one-dimensional” management often seen when a manager with little or no experience in cave or karst issues takes on the role of the cave specialist or manager. This is evident when a biologist, for example, drives biology-specific management without consideration of the additional complex components of the cave and karst environment. The incorporation of a specialist, such as a bat biologist, into cave and karst management is important but it does not alleviate the need to have all the resources represented as together they are what make caves and karst management so dynamic. Unfortunately, one-dimensional management is often relied upon when funding does not allow for fulfillment of a holistic view of meeting resource needs.

Without the structure of a cave and karst program within the unit, it is common practice to manage reactively as opposed to a science-based, proactive management approach. In smaller units and units with limited resources reactive management might be the only option for resource management but should not be considered appropriate for resource needs. With limited resources and funding adequate protection is compromised. Marginally successful cave and karst protection in these conditions, notably outside of adherence to policy and guidelines, has been achieved through collaboration with other units including the NPS Cave and Karst Program, the National Cave and Karst Research Institute (NCKRI) and non-governmental organizations with a strong research presence.

These situations are understandably common based on limited cave and karst resources, available personnel, and funding restraints. Such limitations are not isolated to cave and karst resources within the federal government though cave and karst resource have been provided congressional attention to alleviate these inconsistencies (Huppert 1995). Often, these duties and responsibilities are absorbed by a non-specialist. In the context of cave and karst management, the use of this approach often generates results that fall short of the needs of effective protection of cave and karst resources, as the focus on cave and karst issues is often limited in scope.

GRSM's cave and karst resources are of a quality and magnitude requiring significant protection and adherence to mandated policy and guidance. Compared to cave resources on NPS managed land across the country, GRSM caves and karst are very unique and require specific attention to prevent their degradation. GRSM's current use of the Superintendent's Compendium does provide some management structure but is clearly reactive in nature. This approach lacks the magnitude needed to provide adequate management for cave access and support of caves and karst science in GRSM. Duties defined under the Compendium for caves and karst are addressed by a variety of divisions further complicating the needed centralization of management.

Case Study: GRSM Management

In understanding what is known about cave and karst resources of GRSM, an assessment of best practices in cave and karst management on other federally managed lands suggests the need for a specialist to develop a dynamic cave and karst program specific to the needs of GRSM's resources as well as to support the objectives of RM#77. Other parks, like GRSM, whose cave and karst resources are not the primary concerns of the park that have done this (e.g. Sequoia and Kings Canyon National Park [SEKI]) have been extremely successful in fulfilling these needs. It is important to note that SEKI has invested in a commercial cave within the park and strongly affects the need to be proactive with cave management. Unfortunately, because of the nature and complexity of GRSM as well as the extant of park resources and management concerns beyond that of caves and karst, this approach has not been considered internally. Within the confines of the Resource Management and Science Division's capabilities to manage caves and karst, a compilation of known resources and development of a cave and karst management plan is a necessary starting point to fulfill not only the primary policy objectives but also to define the needs of park resource protection. A specific management plan will provide, on paper, the consistency needed to fulfill the NPS mission, relevant policy, and documented guidelines. Implementation will solidify the management for consistent protection.

-Afforded Protection: Cave Management through Reactive and Proactive Measures

The idea of a cave-focused management plan for GRSM is supported by the FCRPA which clearly states that the purpose of the policy is to secure, protect, and preserve significant caves. The Department of the Interior CFR Title 43 Part 37 mimics this focus and addresses the needs of the management of caves. In their definition of "[significant] cave" and its protection we only see the protection focus placed on components or issues affecting the cave. Herein lies a simple problem that becomes relevant when caves are either unknown or simply not present.

In the case of GRSM, the management of caves will protect much of the karst environments but not all. Included in this protection would be the karst terrain of the most cavernous portions of the greater Cades Cove area, all of the drainage and karst areas of the highly dynamic White Oak Sink and the Bull Sink area. In addition, the management of the Foothills Parkway System around Stupka (Myrh) Cave and the Foothills Parkway Cave at Walland would minimally include the needed protection of karst areas surrounding them—some of which might incorporate non-park lands in their suggested protection.

The concentration on cave management, which is based on acts of Congress and DOI management regulations alone would not focus on karst areas lacking caves. The policy is generally not applied directly to karst topography, which lacks significant caves by definition. Even with all caves designated as significant on NPS managed land, a large portion of karst topography would be left unprotected. Lacking protection in GRSM would be karst areas of Cades Cove with colluvial overburden, the entire Big Spring Cove karst area, potential karst development in the Calderwood area, and several portions of the Foothills Parkway System. Loosely, over half of the karst in GRSM would see little protection. Potentially other significant portions of karst might be left unprotected where inability to understand karst processes could detach them from adjacent cave systems. One example would be along GRSM's boundary at Scott Gap where surface topography would seem to apply protection from development outside and somewhat down slope of the crest of the ridge. The subterranean flow paths in this area are unknown and might affect GRSM caves by flowing south, into the mountain and ultimately into GRSM caves or minimally into the White Oak Sink Aquifer, which ultimately provides recharge to Dry Valley. Lastly, as new caves are discovered around the park yearly, park areas with karst thought to be void of caves could yield additional cave resources in the future. One such area of interest is along Rich Mountain where large cave systems have been discovered and speculation of others continues to tempt explorers. In this area and others, management of karst is crucial to protect these yet to be discovered resources.

-Afforded Protection: Proactive Karst Management

Further interpretation of RM#77 specifically addresses the need to incorporate karst issues into park resource management planning. As stated in the first paragraph under Karst [Management]:

> "*The Service will manage karst terrain to maintain the inherent integrity of its water quality, spring flow, drainage patterns, and caves. Karst processes (the processes by which water dissolves soluble rock such as limestone) create areas typified by sinkholes, underground streams, caves, and springs.*"

This objective in RM#77 appears to be often overlooked in GRSM and other non-cave parks with reactive cave resource management. That is not to say that these parameters are not considered at all but that the need to fully understand karst resources can impose "*unique conditions and challenges*" and are considered "*some of the most complex and intricate hydrological and ecological systems within a park*" (RM#77). To date, much of the basic RM#77 cave and karst guidance has not been applied to GRSM needs. The incorporation of much of RM#77 guidance is supported throughout the science of karst and cave management in the literature. As stated in RM#77:

A park's cave management program should include:

1. *protection of natural processes in cave ecosystems and karst landscapes;*
2. *scientific studies and research in or about cave and karst resources and systems, to increase the park's scientific knowledge and broaden the understanding of its cave resources and karst processes;*
3. *detailed cartographic survey of caves and cave systems and a detailed inventory of resources within cave systems;*
4. *provision for educational and recreational opportunities for a broad spectrum of park visitors to safely visit, study, and enjoy caves at a variety of levels of interest and abilities;*
5. *establishment of regulations, guidelines, and/or permit stipulations that will ensure maximum conservation of cave resources and karst processes;*
6. *direction for cave restoration activities that remove unnatural materials or restore otherwise impacted areas;*

7. *establishment of standard operating procedures in the maintenance and upkeep of developed cave passages;*
8. *monitoring of natural environmental conditions and visitor use and impact;*
9. *protection of related cultural and biological resources; and*
10. *methods for sustainable use of cave resources.*

RM#77 guidelines are consistent with other federal and state land managing agency guidelines bound by the FCRPA even though their individual agency missions vary greatly. GRSM and other park units can gain considerable insight on how to plan for these types of nontraditional anthropogenic effects on their karst environments with structured proactive management. On the Tongass National Forest (TNF) in Southeast Alaska's Alexander Archipelago, for example, karst specialists specifically manage karst areas regardless of cave development. One of the primary concerns is the influx of sediments and debris into sinkholes and karst aquifers during and post timber harvest. Within the TNF's karst management guidelines is the ability to rate the vulnerability of the karst terrain as a transport mechanism for sediments as well as to afford protection to karst landscape features as well. Though not a NPS unit, the TNF's afforded protection to karst areas lacking known caves is necessary to protect forest resources and processes in conjunction with their diverse multi-use land management. Their methodology and focus on karst protection can be used to understand the importance of karst specific management outside of caves. Although NPS-managed lands are generally not subject to timber harvest they are receiving increasing visitation yearly, which has required the need for infrastructure development, which has similar irreversible effects on karst, specifically sediment and pollution transport.

Karst protection on the TNF as well as seen through proactive management on select NPS units support the use of RM#77 guidelines in developing best practices for karst on NPS lands. The incorporation of a holistic, karst-based approach to protection of these resources is inline with current karst science and land use management and successful karst protection across the globe. This is especially true in areas where karst resources, such as karst ground water quality in developing countries, affect human health and environmental conditions. In following the NPS mission, the protection of these resources should not fall short of preservation. GRSM contains parts of karst drainage systems that flow to springs outside of the park, which supply the source of water for neighboring communities. These communities on karst, where ground water originates within the boundaries of GRSM, are extremely sensitive to how GRSM manages their karst areas. GRSM, as a steward of the land, not only has a responsibility to these communities but also an opportunity to develop better practices on karst in the region by initiating positive relationships with these communities. This type of relationship will come into play as karst areas are further developed along the park boundary where karst environments exist. Furthermore, as karst pathways are better understood along GRSM borders, negative impacts to karst resources can be prevented both within and outside of GRSM. Where federal acts fall short of holistic land management, RM#77 provides a mechanism of structured guidance to meet these shortcomings and manage congruently with karst science.

The extensive nature in employing RM#77 again supports the development of a cave and karst program specific to GRSM needs. Included in that program must be a specific set of guidelines and references providing the needed information for consistent management. The development of a management plan must address the most basic policy needs as well as the incorporation of park specific guidance to be effective. The Draft Cave and Karst Management Plan for GRSM (Appendix C) should be considered a working draft capable of advancing GRSM's management of these resources. Crucial to the success of the management plan is the implementation with provisions for adaptive management.

Survey results from NPS units show a consistent set of management concerns, which are applicable to GRSM. As might be expected, current threats and challenges are similar across many units. GRSM shares many of the basic issues threatening other NPS and federal unit's karst and cave environments. Consistent with Table 2, GRSM's primary anthropogenic issues are: illegal and legal cave access monitoring and management, the inventory and monitoring including the degradation of physical and biological cave and karst resources, non-native concerns (WNS), and the need for proactive management of the karst system internally and external to the park boundary to understand and prevent surface actions from deteriorating cave and karst resources. In addition to these anthropogenic concerns, GRSM must encourage additional research to support management direction (Table 1) as well as develop outreach education programs for the nine million visitors who visit GRSM each year and are unaware of the dynamic cave and karst resources. The management plan developed in the context of this research has taken an in-depth look at these issues to address GRSM needs.

This cave and karst management plan is complete but should be considered a draft. GRSM carries the additional responsibilities to see that the plan receives mandated internal and external review. The management plan should receive regular reviews to keep it relevant and up to date with new discoveries as well as current science-based management. Consistent review of the plan will provide the resource the benefits of adaptive management, ensuring that future protection will be granted to the changing needs of the resource. As cave and karst science evolves and use of these resources change, management must adapt to these changes to fulfill applicable policy and guidelines. The development of a plan to guide management creates a foundation to support adaptive management and ensures the perpetual protection of the resource parallel to and in conjunction with the NPS mission.

This research, though comprehensive for GRSM management, is limited in its direct application for all NPS units. The theory and background on federal cave and karst management as well as the need for holistic proactive management is applicable across a wide range of NPS units, which mimic reactive management of caves and karst. The survey results did not recover substantial information from federal land managing units other than the NPS. Though responses from NPS units were low, interest in retrieving returns from NPS units provided enough results to clearly show the consistency in cave and karst needs qualitatively. GRSM as a case study provides a solid representation of the needs and requirements of cave and karst resources on NPS managed lands. In addition to the above shortcomings in wide range application, much of the management application components within the management plan are qualitative in that there is more than one possible solution to the problem. The bases for choosing certain pathways over others is directly related to the complexity and intimate knowledge of GRSM cave and karst resources as well as the interpretation of the greatest concerns for the resource.

Conclusions

- Federal Policy and specific guidelines support a need to fulfill management requirements, including development of management plans and proactive programs, to affording protection of cave and karst resources on federal lands bound by the FCRPA.
- In addition to federal legislation on cave and karst management, the NPS' mission and Organic Act provide opportunity for enjoyment and scientific use of caves and karst areas as long as such activities do not leave the resource impaired.
- Required under RM-77 and other legislation, the NPS is required to manage beyond the boundaries of cave environments to include the karst ecosystem holistically.
- Policy-based management of caves can leave karst topography vulnerable where caves are unknown.
- Landscape-wide karst environment management is supported in the literature but lacks the magnitude placed on cave management through federal policy.
- Landscape-wide karst assessment and the proactive need to develop a GRSM specific cave and karst management plan are supported in the literature and in the governing policy and guidelines.

- Development of a specific cave and karst management plan must meet the needs of the resource as well as consider stakeholder involvement within the confines of the NPS mission and Organic Act.
- As cave and karst management is dynamic, GRSM needs to incorporate an adaptive management approach to cave and karst resource management.

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Chapter VII: Appendices

Appendix A.

Federal Agency Level Cave and Karst Manager Questionnaire

Thank you for taking part in this research. Your input is crucial to the success of this project, and your time is greatly appreciated. This research is under the direction of Daniel Nolfi, MS Candidate, and Dr. Chris Groves, Director, Hoffman Environmental Research Institute, Department of Geography and Geology at Western Kentucky University. The research is exploratory, and findings from this survey may be used in a written research paper, aspects of which may contribute to reports, publications and presentations at scientific and/or resource management conferences. As reports and publications resulting from this research may be used by a variety of government and non-government agencies in assessing management protocols, your answers are important, and we appreciate your thoughtful responses.

The survey consists of a series of questions related to the management and protection of cave and karst resources by U.S. Federal Land Management Agencies. These questions are designed to assess existing knowledge and capacity for study of known and unexplored cave and karst resources. In addition, the survey will investigate collaboration with outside agencies and organizations related to study of cave and karst resources.

Your participation in this research is voluntary, and if you feel that you are not the proper contact in regards to cave and karst resources in your management area, please contact Daniel Nolfi (Daniel_Nolfi@nps.gov), (865)206-6921 so that we may redirect the survey.

Again, thank you very much for your participation. If you have any questions, please feel free to contact us. If you have questions about your rights as a research participant, please call the Office of Sponsored Programs at Western Kentucky University, (270) 745-2129.

Instructions:

Please answer the questions in each section to the best of your knowledge. If you are unsure about any answer, or there is no existing data, please indicate that in your response.

You may fill out the survey by typing in the shaded areas below each question. You may then save the form, and return electronically by email (Daniel_Nolfi@nps.gov).

At the end of the survey, please feel free to include additional information, resources or references you think may be of use to the investigators.

Please tell us a little bit about yourself:

Name:

Title:

Agency:

Management area:

Telephone:

Fax Number:

Email Address:

Section 1

Questions in this section are designed to gather baseline data about existing knowledge of cave and karst resources and management on federally managed lands.

This section is 2 pages (including [this] cover page).

Section 1

1) What is the total acreage managed by your agency?

What is the total number of units managed by your agency?

3. How many of these units have identified and documented cave and karst resources?

4. How many caves have been identified and documented, in total, across all managed units? Please note whether approximate or exact numbers.

5. How many units have a staff member devoted specifically to management of cave and karst resources (cave and karst specialist)?

6. How many units have **unit-specific** cave and karst management plans THAT HAVE BEEN IMPLEMENTED?

7. How many units have **unit-specific** cave and karst management plans IN PROCESS?

8. How many units have **cave-specific** cave and karst management plans THAT HAVE BEEN IMPLEMENTED?

9. How many units have **cave-specific** cave and karst management plans IN PROCESS?

Section 2

Questions in this section are designed to gain a better understanding of the nature of research and scientific knowledge related to identified and documented cave and karst resources.

This section is 2 pages (including [this] cover page).

Section 2

1. Does your agency currently and actively pursue research/scientific study of cave and karst resources?

   ☐ Yes ☐ No

2. If yes, what types of research and scientific study have been completed, or are currently underway in regards to cave and karst resources?

3. Are your agency-wide current cave and karst management practices affected by research findings? If yes, please explain.

   ☐ Yes ☐ No

4. Please identify what you see as current threats to cave and karst areas in units managed by your agency.

Section 3

Questions in this section are designed to explore existing relationships and opportunities with outside agencies/entities in furthering the study and management of cave and karst resources on federally managed lands.

This section is 2 pages (including cover page).

Section 3

Does your agency currently have, or have you in the past had a relationship with an outside agency/entity in regards to the scientific study of cave and karst resources?

☐ Yes ☐ No

If no, you have completed the questionnaire. Thank you for your participation.

If yes, please answer the questions below:

1. List the agencies/entities below:

2. Are any of the relationships formally recognized (e.g., Memorandum of Understanding), or are the relationships informal in nature? If yes, please describe:

3. In thinking about the relationships with outside agencies/entities, please describe how the outside agency/entity became involved in the scientific study of cave and karst areas. For example, did your agency actively engage the agency/entity? Or, was your agency approached by the outside agency/entity with a request to conduct research?

Please feel free to include additional information, resources or references you think may be of use to the investigators.

Federal Unit Level Cave and Karst Managers

Thank you for taking part in this research. Your input is crucial to the success of this project, and your time is greatly appreciated. This research is under the direction of Daniel Nolfi, MS Candidate, and Dr. Chris Groves, Director, Hoffman Environmental Research Institute, Department of Geography and Geology at Western Kentucky University. The research is exploratory, and findings from this survey may be used in a written research paper, aspects of which may contribute to reports, publications and presentations at scientific and/or resource management conferences. As reports and publications resulting from this research may be used by a variety of government and non-government agencies in assessing management protocols, your answers are important, and we appreciate your thoughtful responses.

The survey consists of a series of questions related to the management and protection of cave and karst resources by U.S. Federal Land Management Agencies. These questions are designed to assess existing knowledge and capacity for study of known and unexplored cave and karst resources. In addition, the survey will investigate collaboration with outside agencies and organizations related to study of cave and karst resources.

Your participation in this research is voluntary. If you feel you are not the proper contact in regards to cave and karst resources in your management area, please contact Daniel Nolfi (Daniel_Nolfi@nps.gov), (865)206-6921 so that we may redirect the survey.

Again, thank you very much for your participation. If you have any questions, please feel free to contact us. If you have questions about your rights as a research participant, please call the Office of Sponsored Programs at Western Kentucky University, (270) 745-2129.

Instructions:

Please answer the questions in each section to the best of your knowledge. Please do not leave any questions unanswered. If you are unsure about any answer, or there are no existing data, please indicate that in your response.

You may fill out the survey by typing in the shaded areas below each question. You may then save the form, and return electronically by email (Daniel_Nolfi@nps.gov).

At the end of the survey, please feel free to include additional information, resources or references you think may be of use to the investigators.

Please tell us a little bit about yourself:

Name:

Title:

Agency:

Management area:

Telephone:

Fax Number:

Email Address:

Section 1

Questions in this section are designed to gather baseline data about existing knowledge of cave and karst resources and management in your management area.

This section is 3 pages (including cover page)

Section 1

1. What is the name of the unit and what is the federal land management agency responsible for management of the unit?

2. What is the total acreage of the unit?

3. How many caves have been identified and documented in the unit? What is the general extent of the cave system(s)?

4. How many identified and documented caves are open for public use?

5. How many identified and documented caves are restricted for public use?

6. Does the unit have a **unit-specific** cave management plan that has been IMPLEMENTED?

   ☐ Yes ☐ No

7. Does the unit have a **unit-specific** cave management plan IN-PROCESS?

   ☐ Yes ☐ No

8. Does the unit have a **cave-specific** cave management plan(s) that has been IMPLEMENTED? If yes, how many?

   ☐ Yes ☐ No

9. Does the unit have a **cave-specific** cave management plan(s) IN-PROCESS? If yes, how many?

☐ Yes ☐ No

10. Does the unit have a permitting process for those wishing to enter caves that are not open to the public?

☐ Yes ☐ No

11. If yes, does permitting appear to be increasing, decreasing, or remaining about the same for:

    1. Scientific study

    2. Recreational use

12. Do enforcement actions (related to cave resources) appear to be increasing, decreasing, or remaining about the same?

Briefly describe specific management actions (e.g., gate installation, trail closures) related to cave and karst management in the unit.

Section 2

Questions in this section are designed to gain a better understanding of the nature of research and scientific knowledge related to identified and documented cave and karst resources.

This section is 3 pages (including cover page).

Section 2

2. Is there currently an active program of research/scientific study of the cave and karst resources in your unit?

☐ Yes ☐ No

3. If yes, what types of research and scientific study have been completed, or are currently underway in your unit? Please explain briefly what type(s) of study, if any, has been completed in each of the following areas:

    4. Survey and mapping

    2. Geological

    3. Hydrological

    4. Biological

    5. Archeological

    6. Paleontological

    7. Other (please identify)

3. Are your current cave and karst management practices affected by research findings? If yes, please explain.

☐ Yes ☐ No

4. Please identify what you see as current threats to cave and karst areas in your unit.

5. Briefly describe what you see as the major challenges in managing cave and karst areas in your unit.

Section 3

Questions in this section are designed to explore existing relationships and opportunities with outside agencies/entities in furthering the study and management of cave and karst resources on federally managed lands.

This section is 2 pages (including cover page).

Section 3

Does your unit currently have, or have you in the past had a relationship with an outside agency/entity in regards to the scientific study of cave and karst resources within the unit?

☐ Yes ☐ No

If no, you have completed the questionnaire. Thank you for your participation.

If yes, please answer the questions below:

1. List the outside agencies/entities:

2. Are any of these relationships formally recognized (e.g., Memorandum of Understanding), or are the relationships informal in nature? If yes, please describe:

3. In thinking about the relationships with outside agencies/entities, please describe how the outside agency/entity became involved in the scientific study of cave and karst areas in your unit. For example, did your unit actively engage the agency/entity? Or, did the outside agency/entity approach your unit with a request to conduct research?

Please feel free to include comments, additional information, resources or references you think may be of use to the investigators:

Appendix B

Organisms associated with caves and karst in Great Smoky Mountains National Park

Species	Common name	level	Record location	Citation
Acanthocyclops exilis	arthropod	AC	RBC	Reeves 2000
Achaeranea sp.	spider	UK	MYC	Reeves 2000
Acroneuria abnormis	stonefly	AC	RBC	Reeves 2000
Aecothea fidelis	heleomyzid fly	TX	GRC	Mays 2002
Aecothea specus	heleomyzid fly	TX	CC1, GRC, MYC, RMB, SPC, WOB	Reeves 2000
Aecothea specus	heleomyzid fly	TP, TX	MYC	Wallace 1984, 1989
Agkistodon contortrix	copperhead	n/a	GRC	Dodd et al. 2001
Aloconota laurentiana	terrestrial	TP	GRC	Mays 2002
Amoebaleria defessa	fly	TX	CC1, GRC, MYC, RMB, SPC, WOB	Reeves 2000; Mays 2002
Amoebaleria defessa or Heleomyza brachypterna	fly	TX	GRC	Wallace 1984, 1989
Anguispira mordax	Appalachian disc snail	n/a	WOS	DLIA 2007
Anillinus sp.	beetle	UK	SPC	Reeves 2000
Anopholes defessen	fly	TX	GRC, MYC, WOB	Reeves 2000
Antrodiaetus sp.	trapdoor spider	AC	MYC	Wallace 1984, 1989, 1990
Antrodiaetus unicolor	spider	TP	MYC	Reeves 2000
Apheloria montana	millipede	AC	RMB	Reeves 2000
Aporrectodea sp.	earthworm	TP	WOB	Reeves 2000
Appalachina chilhoweensis	Queen crater snail	n/a	WOS	DLIA 2007
Arrhopalites sp.	springtail	TP	GRC	Mays 2002
Asplenium rhyzophyllum	walking fern	n/a	BLC	DLIA 2007
Atheta annexa	terrestrial fungivore	TP	GRC	Mays 2002
Bimastos zeteki	earthworm	TP	SPC	Reeves 2000
Bishopella laciniosa	harvestman	TP	CC1, RMB	Reeves 2000
Bradysia forficulata	fly	TP	WOB	Reeves 2000
Bufo americanus	American toad	n/a	GRC	Dodd et al. 2001
Bufo fowleri	Fowler's toad	n/a	GRC	Dodd et al. 2001

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregory Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; RMB= Rich Mountain Blowhole; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink

Adaptation level key: AC= accidental; TB= troglobite; TP= troglophile; TX= trogloxene; UK= unknown; n/a= species associated with karst area

Cambala hubrichti	millipede	TP	CC1, CC2, GRC, MYC, SGC, SPC, TSB, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002; DLIA 2007
Cambarus bartonii	crayfish	TP	MYC, RBC	Reeves 2000
Camponotus americanus	ant	AC	RMB	Reeves 2000
Carphophis amoenus	Eastern wormsnake	n/a	GRC	Dodd et al. 2001
Carychium clappi	Appalachian thorn snail	n/a	WOS	DLIA 2007
Carychium exiguum	obese thorn snail	n/a	GRC, WOS	DLIA 2007
Carychium exile	Ice thorn snail	n/a	WOS	DLIA 2007
Carychium mexicanum	Southern thorn snail	n/a	WOS	DLIA 2007
Carychium nannodes	File thorn snail	n/a	RMB, WOS	Reeves 2000, DLIA 2007
Catops gratiosus	beetle	TP	MYC	Reeves 2000
Ceuthophillus spp.	cricket	TX	CC1, CC2, GRC, MYC, RMB, SGC, TSB, WOB	Wallace 1984, 1989, 1990; NPS 1994; Reeves 2001; Mays 2002
Chthonius nr paludis	psuedoscorpion	UK	GRC	Reeves 2000
Cochlicopa morseana	Appalachian pillar snail	n/a	WOS	DLIA 2007
Cordulegaster erronea	Tiger spiketail dragonfly	AC	RBC	DLIA 2007
Culex erraticus	mosquito	TX	GRC, MYC	Reeves 2000
Culex spp.	mosquito	TX	GRC	Mays 2002
Cybaeus patritus	spider	TP	SGC, WOB	Reeves 2000
Dendrodrilus rubidous	earthworm	TP	CC1, GRC, WOB	Reeves 1999, Reeves 2000
Desmognathus conanti	spotted dusky salamander	n/a	BLC, CC1, CC2, WOS	Dodd et al. 2001
Desmognathus fuscus fuscus	dusky salamander	AC	WOB	Wallace 1984, 1989
Desmognathus quadramaculatus	black bellied salamander	AC	RBC	Wallace 1984, 1989
Dichocera lyrata	fly	UK	RMB	Reeves 2000
Discus nigrimonatanus	Black mountain disc snail	n/a	WOS	DLIA 2007
Discus patulus	Domed disc snail	n/a	WOS	DLIA 2007
Dolomedes vittatus	spider	TX	GRC, MYC, SPC	Reeves 2000
Dorypteryx pallida	fly	UK	RMB	Reeves 2000

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Adaptation level key: AC= accidental; TB= troglobite; TP= troglophile; TX= trogloxene; UK= unknown; n/a= species associated with karst area

Eclipidrilus or Rhynchelmis sp	earthworm	TP	MYC	Reeves 2000
Elaphe obsoleta	Black ratsnake	n/a	GRC	Dodd et al. 2001
Eptesicus fuscus	big brown bat	TX	GRC, SPC	Wallace 1984, 1989
Euconulus dentatus	snail	n/a	WOS	DLIA 2007
Euconulus trochulus	snail	n/a	WOS	DLIA 2007
Euhadenoecus spp.	cricket	TX	GRC, MYC, WOB	Wallace 1984, 1989, 1990; NPS 1994; Mays 2002; DLIA 2007
Eurycea bislineata bislineata	Northern two-lined salamander	AC	GRC	NPS 1995
Eurycea bislineata wilderae	Blue Ridge two-lined salamander	AC	BLC, CC1, CC2, GRC, WOB, WOS	Wallace 1984, 1989; Dodd et al. 2001; DLIA 2007
Eurycea longicauda	long-tailed salamander	TX	GRC, MYC	Wallace 1984, 1989, 1990; Dodd et al. 2001; Taylor and Mays 2006; DLIA 2007
Eurycea lucifuga	cave salamander	TX	CC2, MYC, WOB	Wallace 1984, 1989, 1990; Dodd et al. 2001
Euschoengastia pipistrelli	parasite	UK	GRC, SPC	Reeves 2000
Exechiopsis shawi	fungus gnat	TX	GRC	Mays 2002
Folsomia candida	springtail	TP	WOB	Reeves 2000
Fumonelix christyi	glossy covert snail	n/a	WOS	DLIA 2007
Gastorcepta contracta	snail	n/a	WOS	DLIA 2007
Gastorcepta corticaria	snail	n/a	WOS	DLIA 2007
Gastrocepta pentadon	snail	n/a	WOS	DLIA 2007
Gerris sp.	water strider	AC	RBC	Wallace 1984, 1989; Reeves 2000
Glyphyalinia caroliniensus	snail	n/a	WOS	DLIA 2007
Glyphyalinia indentata	snail	n/a	GRC, WOS	DLIA 2007
Glyphyalinia wheatleyi	snail	n/a	WOS	DLIA 2007
Gordionus lineatus	internal parasite	UK	SPC	Reeves 2000
Guppya sterekii	snail	n/a	WOS	DLIA 2007
Gyrinophilus porphyriticus	spring salamander	TP	BLC, WOB	DLIA 2007
Gyrinophilus porphyriticus danielsi	Blue Ridge spring salamander	TP	RBC, WOB	Wallace 1984, 1989

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregory Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; RMB= Rich Mountain Blowhole; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink

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Hadenoecus sp.	cricket	TX	BLC, CC1, GRC, MYC, RMB, SGC, SPC, TSB, WOB	Wallace 1984, 1989; Reeves 2000
Haplotrema concavum	snail	n/a	GRC, WOS	DLIA 2007
Hawaiia minuscula	snail	n/a	WOS	DLIA 2007
Hyla chrysoscelis	Copes gray tree frog	AC	SDC	DLIA 2007
Hypochilus pococki	spider	TX	GRC, MYC, RMB	Reeves 2000; Mays 2002; DLIA 2007
ypochilus thorellii	lamp shade spider	TX	GRC, MYC	Wallace 1984, 1989, 1990
Inflectarius rugeli	snail	n/a	GRC, WOS	DLIA 2007
Isotoma cf. manitobae	springtail	TP	WOB	Reeves 2000
Isotoma notabilis	springtail	TP	GRC, WOB	Reeves 2000, Mays 2002
Lampropeltis triangulum	milksnake	n/a	TSB	Dodd et al. 2001
Latrodectus variolus	spider	AC	GRC	Mays 2002
Leiobunum calcar	harvestman	TX	BLC, RMB	Reeves 2000
Leiobunum elegans	harvestman	TX	BLC, CC1, GRC, MYC	Reeves 2000; Mays 2002
Lepidocyrtus cf. beaucatcheri	springtail	TP	WOB	Reeves 2000
Lepisma sp.	silverfish	TP	GRC	Reeves 2000
Limonia cinctipes	fly	TX	RMB	Reeves 2000
Limonia rara	fly	TX	RMB	Reeves 2000
Liocranoides coylei	spider	TP	BLC, GRC, RMB, WOB	Reeves 2000; Mays 2002
Liposcelis decolor	lice	TP	GRC, RMB, WOB	Reeves 2000
Lymeon sp.	mite	AC	GRC	Mays 2002
Maymena ambita (barrows)	terrestrial predator	TP	GRC	Mays 2002
Megaselia cavernicola	fly	TP	GRC	Mays 2002
Megaselia sp.	fly	TP	GRC, RMB, SGC	Reeves 2000
Mesodon clausus	snail	n/a	WOS	DLIA 2007
Mesodon normalis	snail	n/a	GRC, WOS	DLIA 2007
Mesodon zaletus	snail	n/a	WOS	DLIA 2007
Mesomphix andrewsae	snail	n/a	WOB, WOS	Reeves 2000
Mesomphix cupreus	snail	n/a	WOS	DLIA 2007
Mesomphix inornatus	snail	n/a	GRC	DLIA 2007
Mesomphix perlaevis	snail	n/a	WOS	DLIA 2007
Meta menardi	orb weaver	n/a	TSB	Wallace 1984, 1989

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregory Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; RMB= Rich Mountain Blowhole; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink

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Meta ovalis	spider	TP	MYC, SPC, WOB	Reeves 2000
Mycetophila ichneumonea	fungus	TX	GRC	Mays 2002
Myotis eenii	fungus gnat	TX	WOB	Wallace 1984, 1989
Myotis lucifugus	little brown bat	TX	WOB	Wallace 1984, 1989
Myotis sodalis	Indiana bat	TX	BLC, SCG, WOB	Wallace 1984, 1989
Nampabius sp.	centipede	UK	GRC, RBC	Reeves 2000; Mays 2002
Necrophius pettiti	beetle	TP	MYC	Reeves 2000
Nesticus sp.	spider	TB, TP	CC1, SDC	Wallace 1984, 1989
Nesticus stupkai	spider	TP	BLC, CC1, MYC, TSB, WOB	Wallace 1984, 1989, 1990; NPS 1992; Reeves 2000; DLIA 2007
Notopthalmus viridescens	newt	AC	BLC, CC1, CC2, MYC, WOS	Dodd et al. 2001
Octolasion tyrataeum	segmented worm	TP	CC1	Reeves 2000
Onthophagus striatulus	beetle	TX	RMB	Reeves 2000
Onychiurus cf. subtenuis	springtail	TP	WOB	Reeves 2000
Oreonetides flavus	spider	TP	BLC	Reeves 2000
Pallifera dorsalis	snail	n/a	WOS	DLIA 2007
Paravitrea mplacentula	snail	n/a	WOS	DLIA 2007
Paravitrea multidentata	snail	n/a	WOS	DLIA 2007
Patera perigrapta	snail	n/a	GRC, WOS	DLIA 2007
Pericoma nr. scotiae	fly	TP	MYC	Reeves 2000
Pericoma signata	fly	TP	RMB	Reeves 2000
Phagocata morgani	flatworm	UK	BLC	DLIA 2007
Philomycus carolinianus	snail	n/a	GRC, WOS	DLIA 2007
Phora sp.	fly	TP	GRC, RMB, SGC	Reeves 2000; Mays 2002
Phronia sp.	gnat	TX	MYC	Reeves 2000
Perimyotis subflavus	Tri-colored bat	TX	BLC, CC2, GRC, MYC, RBC, SGC, SPC, WOB	Wallace 1984, 1989, 1990; NPS 1990, NPS 1994, NPS 1995; NPS 1996; DLIA 2007

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregory Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; RMB= Rich Mountain Blowhole; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink
Adaptation level key: AC= accidental; TB= troglobite; TP= troglophile; TX= trogloxene; UK= unknown; n/a= species associated with karst area

Corynorhinus rafinesquii	Rafinesque's big-eared bat	TX	GRC, MYC, SGC	Wallace 1984, 1989, 1990
Plethodon glutinosus	slimy salamander	TX	BLC, CC1, CC2, GRC, MYC, RBC, SDC, WOB, WOS	Wallace 1984, 1989, 1990; Dodd et al. 2001; Taylor and Mays 2006; DLIA 2007
Plethodon serratus	red-backed salamander	n/a	BLC, CC1, CC2, GRC, WOS	Dodd et al. 2001
Plethodon ventralis	Southern zigzag salamander	n/a	BLC, WOS	Dodd et al. 2001
Pomaliopsis lapidaria	snail	n/a	WOS	DLIA 2007
Procyon lotor	raccoon	TX	TSB	Wallace 1984, 1989
Pseudopolydesmus serratus	terrestrial omnivore	TX	GRC	Mays 2002
Pseudosinella sp (sexuculata complex)	springtail	TP	GRC	Mays 2002
Pseudosinella cf. christianseni	springtail	TP	RMB	Reeves 2000
Pseudosinella cf. gisini	springtail	TP	WOB	Reeves 2000
Pseudosinella collina	springtail	TP	WOB	Reeves 2000
Pseudosinella pecki	springtail	TP	GRC	Mays 2002
Pseudotremia fracta	millipede	TP	BLC, CC1, GRC, RMB, SGC, SPC	Reeves 2000; Mays 2002; DLIA 2007
Pseudotriton ruber schencki	black chinned salamander	TX	WOB, WOS	Wallace 1984, 1989
Psychoda sp.	fly	TP	SGC	Reeves 2000
Psychoda unbracla	fly	TP	MYC	Reeves 2000
Psychoda uniformata	fly	TP	RMB	Reeves 2000
Ptenothrix atra	springtail	TP	GRC	Mays 2002
Pterostichus sp.	black beetle	AC	WOB	Wallace 1984, 1989
Punctum minutissiumum	snail	n/a	WOS	DLIA 2007
Punctum vitreum	snail	n/a	WOS	DLIA 2007
Rana clamitans	Northern green frog	AC	BLC, GRC, SDC, WOB	Dodd et al.; DLIA 2007
Rana palustris	Pickerel frog	AC	GRC	Dodd et al. 2001
Rana sylvatica	Wood frog	AC	GRC, SDC	Dodd et al.; DLIA 2007
Rymosia filipes	arthropod	TX	GRC	Mays 2002
Sabacon cavicolens	harvestman	TP	CC1, RMB, SGC	Reeves 2000
Sciara spp.	fly	UK	GRC	Mays 2002

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Scoliopteryx libatrix	moth	TX	MYC, RBC, SPC, WOB	Reeves 2000
Scytonotous australis	terrestrial omnivore	AC	GRC	Mays 2002
Sigmoria fumimontis	millipede	AC	GRC	Mays 2002
Sminthurides lepus	arthropod	TP	GRC	Mays 2002
Stenotrema pilula	snail	n/a	WOS	DLIA 2007
Stenotrema stenotrema	snail	n/a	WOS	DLIA 2007
Striatura meridonalis	snail	n/a	GRC, WOS	DLIA 2007
Strobilops aenea	snail	n/a	GRC, WOS	DLIA 2007
Terrapene carolina	Eastern box turtle	AC	SDC	DLIA 2007
Theromaster brunea	harvestman	UK	RMB	Reeves 2000
Tomocerus dubius	springtail	TP	GRC, RMB, SPC, WOB	Reeves 2000; Mays 2002
Tomocerus sp.	springtail	TP	RMB	Reeves 2000
Trechus tuckaleechee	carabid beetle	TP	RBC, SPC, WOB	Wallace 1984, 1989; Reeves 2000
Trichocera sp.	fly	TX	MYC	Reeves 2000
Tridopsis treidentata	snail	n/a	WOS	DLIA 2007
Ursus americanus	black bear	TX	TSB	Wallace 1984, 1989
Ventridens accera	snail	n/a	WOS	DLIA 2007
Ventridens collisella	snail	n/a	WOS	DLIA 2007
Vertigo gouldi	snail	n/a	WOS	DLIA 2007
Vertigo tridentata	snail	n/a	WOS	DLIA 2007
Wadotes calcaratus	funnel- web spider	TX	MYC	Wallace 1984, 1989, 1990
Xolotrema denotatum	snail	n/a	WOS	DLIA 2007
Zaverelimyia nr thryptica	fly	TP	RBC, RMB, SGC	Reeves 2000
Zonitoides arboreus	snail	n/a	GRC, WOS	DLIA 2007
Zonitoides ellioti	snail	n/a	WOS	DLIA 2007

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregory Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; RMB= Rich Mountain Blowhole; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink

Adaptation level key: AC= accidental; TB= troglobite; TP= troglophile; TX= trogloxene; UK= unknown; n/a= species associated with karst area

Organisms associated with caves and karst in Great Smoky Mountains National Park (identified only to family)

Organism	Common name	Record location (cave)	Citation
Acariformes	water mite	BLC	DLIA 2007
Amphipoda	amphipod	SPC, GRC	Wallace 1984, 1989; DLIA 2007
Araneae	spider	SPC	Wallace 1984, 1989
Astacidae	crayfish	RBC	Wallace 1984, 1989
Cambala	cambala millipede	BLC	DLIA 2007
Cambarincolidae	aquatic/symbiotic	RBC	Reeves 2000
Campodidae	cave dipluran	SGC	Wallace 1984, 1989
Caudata	salamander	GRC, WOB	DLIA 2007
Chilopoda	centipedes	RBC, WOB	Wallace 1984, 1989
Chioptera	bat	GRC, SDC	DLIA 2007
Coleptera	beetle	BLC	DLIA 2007
Collembola	springtail	BLC, MYC, RBC, SGC, SPC, WOB	Wallace 1984, 1989; DLIA 2007
Diplopoda	millipede	SPC	Wallace 1984, 1989
Diplura	wingless dipluran	SDC, WOB	DLIA 2007
Diptera	fly	WOB	DLIA 2007
Foveocheles	arachnid	GRC	Mays 2002
Fungi	wood fungi	WOB	DLIA 2007
Gastropoda	snail	BLC, SDC, WOB	Wallace 1984, 1989; DLIA 2007
Heleomyzidae	fly	BLC, CC1, CC2, GRC, TSB, WOB	Wallace 1984, 1989; DLIA 2007
Lepidoptera	moth	CC1	Wallace 1984, 1989
Linyiiphiidae	sheet web spider	BLC	DLIA 2007
Marchantiophyta	liverwort	BLC	DLIA 2007
Mermithidae	internal parasite	RBC	Reeves 2000
Myotis	bat	BLC	DLIA 2007
Notonectidae	back swimmer	BLC	DLIA 2007
Oligochaeta	earthworm	RBC, WOB	Wallace 1984, 1989; DLIA 2007
Opisthopora	earthworm	BLC	DLIA 2007
Orthoptera	cricket	GRC	DLIA 2007
Parasitidae	terrestrial/unknown	WBC	Reeves 2000
Parholaspididae	terrestrial/unknown	GRC	Reeves 2000
Phalangiidae	harvestmen	CC1, CC2, GRC, RBC	Wallace 1984, 1989
Phoridae	phorid fly	BLC, WOB	DLIA 2007
Protura	terrestrial/unknown	GRC	Reeves 2000
Ptiliidae	terrestrial/unknown	SPC	Reeves 2000
Organism	Common name	Record location (cave)	Citation
Rhagidiidae	terrestrial/unknown	WOB	Reeves 2000
Spirosteptida	millipede	MYC	Wallace 1984, 1989

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Urtica	nettle	BLC	DLIA 2007
Litersapa	diplura insect	WOB	DLIA 2007
Coras	spider	WOB	DLIA 2007
Microcoryphia	jumping bristletail	RBC	DLIA 2007
Helicodiscus	snail	WOS	DLIA 2007
Stenotrema	snail	WOS	DLIA 2007
Blattidae	cockroach	GRC	Mays 2002
Podabrus	beetle	GRC	Mays 2002
Galeritula	beetle	GRC	Mays 2002
Lampyridae	beetle	GRC	Mays 2002
Phyllophaga	beetle	GRC	Mays 2002
Sarcophagidae	fly	GRC	Mays 2002
Psocidae	insect	GRC	Mays 2002

Cave location key: BLC= Bull Cave; CC1 and CC2= Calf Caves 1 and 2; GRC= Gregorys Cave; MYC= Myhr Cave; RBC= Rainbow Falls Cave; SDC= Snakedance Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; TSB= Tory Shields Bluff Cave; WOB= White Oak Blowhole; WOS= White Oak Sink

Appendix C

Great Smoky Mountains National Park

Draft Cave and Karst Management Plan and Resource Assessment

GREAT SMOKY MOUNTAINS NATIONAL PARK

Draft Cave and Karst Management Plan and Resource Assessment

May 2011

Gregorys Cave, Great Smoky Mountains National Park.

Abstract

Great Smoky Mountains National Park (GRSM) encompasses 2,108.76 square kilometers in the states of North Carolina and Tennessee. It receives over 9 million visitors a year, making it the most visited national park in the United States. Karst areas within the Great Smoky Mountains exist in the western portion of the Tennessee side of the park. Current management of cave resources is not based on an approved proactive management plan for caves and karst resources. Management decisions in regards to cave and karst resources currently follow general directives and the park's superintendent's compendium. Great Smoky Mountains National Park's cave and karst resources represent unique resources requiring special management in order to effectively protect them and those who study and recreate within them. Park karst resources, including caves that exhibit extensive vertical relief, support a variety of unique biota and geologic features that attract visitors as popular off trail destinations. Characteristics such as these exemplify the need to address management of these resources.

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Introduction

The Great Smoky Mountains National Park (GRSM) was created in 1934 as the largest national park in the eastern United States. GRSM is an International Biosphere Reserve with 150 square kilometers of old growth forest, the largest continuous tract in the eastern United States. Its forest communities (from 248 to 2025 meters above sea-level) encompass species diversity representative of typical Eastern United States forest communities from Georgia to Maine.

In addition to being designated as an International Biosphere Reserve, the park has also been designated a World Heritage Site by UNESCO. The park maintains 78 historic structures, 10 of which are listed on the National Register of Historic Places, representative of southern Appalachian Mountain communities.

The Great Smoky Mountains, a sub-range of the Appalachian Mountains, exist along the Tennessee and North Carolina border (Figure 1.). The majority of the range is protected in GRSM. The park itself is bordered to the north by the Valley and Ridge Province of the southern Appalachians and to the south by the Blue Ridge Mountains. The primary geology of the Appalachian Mountains is some of the oldest of any mountain range on the planet. GRSM is comprised mainly of members of the Ocoee Supergroup: Precambrian metamorphosed sandstones, phyllites, and slate with the oldest members being gneiss, granite, and schist. Secondarily, the northwestern movement of the Smokies range, in the Allegheny Orogeny, thrust the older metamorphic rock over the younger carbonate rocks of the Upper Cambrian and Lower Ordovician resulting in the current Smokies geology

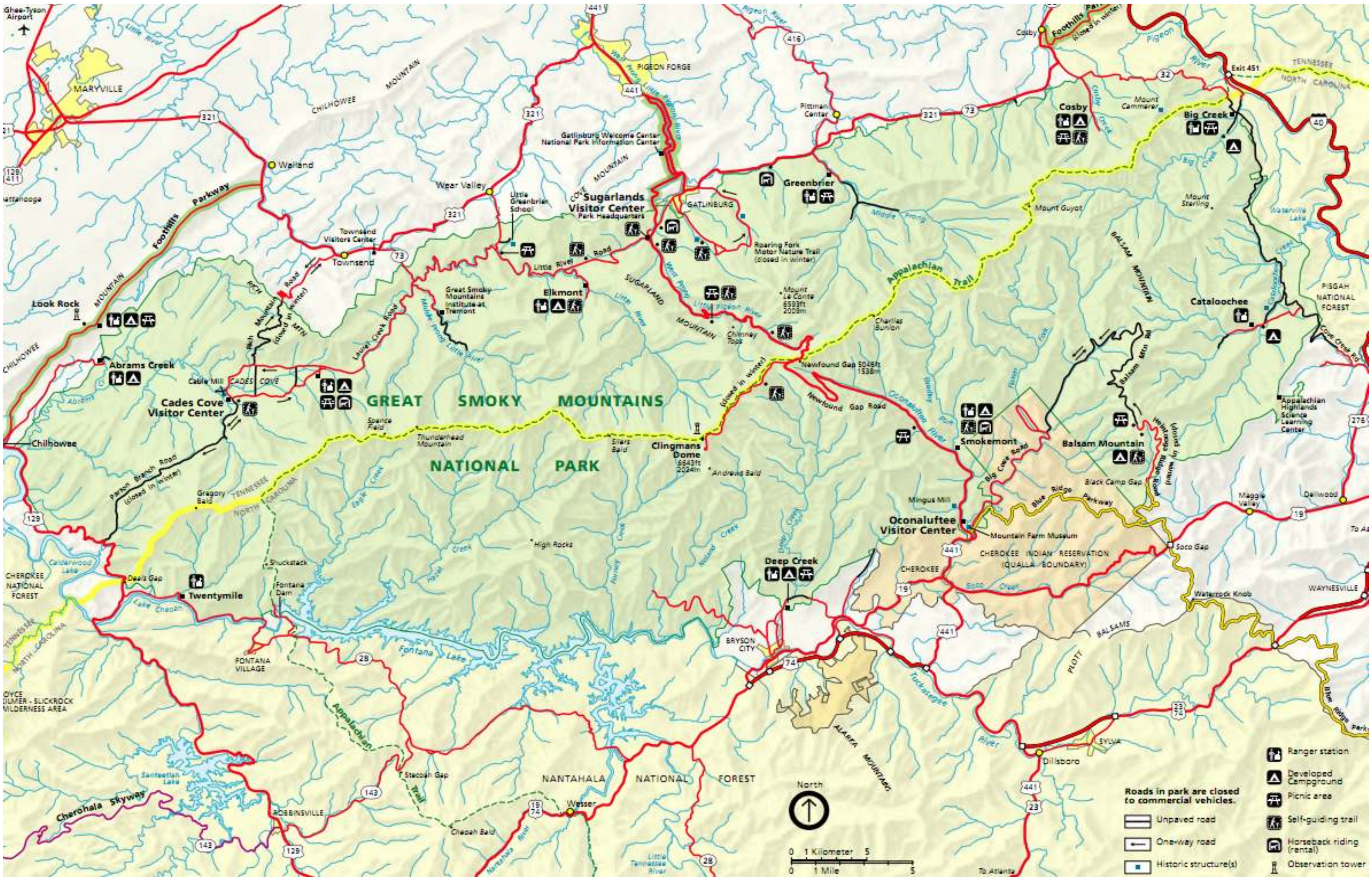

Figure 1. Great Smoky Mountains National Park, North Carolina and Tennessee

(Moore 1988; Houk 1993).

In addition to the complex geology, GRSM is one of the most biologically diverse areas in North America and possibly the world. Currently, an All Taxa Biodiversity Index (ATBI) is being conducted in the park. To date 12,000 of an estimated 100,000 species (12%) have been formally identified, exemplifying the importance to continue study and understanding of the Smokies to preserve and protect it for future generations (Discover Life in America Website [DLIA] 2010).

The diversity of ecotones in GRSM lends itself to the diversity of species that are present. Caves and karst landscapes under management of the Great Smoky Mountains National Park may comprise only a small percentage of the park as a whole but contribute a diversity of species likely incomparable to any other terrain within the park at their size. Many karst-associated species are unlikely to be found in non-karst environments suggesting the need to protect these rare areas. Karst areas in GRSM, together contain sixteen known caves with significant resources, including biological. Several endemic and rare species have been identified in the caves and karst areas of the park. In addition, park caves have been identified as critical habitat for federally listed species.

The complex nature of the geology, representative forest types, altitudinal ecotones, diverse speciation, distinct seasons, and rich culture and heritage exemplify the need to preserve and protect all aspects of the GRSM. Included in this, are the rare and unique cave and karst resources of GRSM.

Legislative history and NPS policy related to cave and karst management

Created in 1916 by the National Park Service Organic Act, the stated mission of the National Park Service (NPS) is "...to promote and regulate the use of the...national parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In May 1926, the United States Congress passed the enabling legislation for the creation of the GRSM in the states of North Carolina and Tennessee. The purpose of the park, based on the NPS mission and the legislative mandate, is to preserve the exceptionally diverse cultural and natural resources, and to provide for the public benefit from and enjoyment of those resources in ways which will leave them basically unaltered by modern human influences.

Management of caves and karst areas on land managed by the NPS is guided not only by the NPS mission, but also by a number of NPS-specific policies and directives and several federal legislative mandates. In 1988, federal legislation provided for specific management and protection of caves on lands managed by the NPS. With the passage of the Federal Cave Resources Protection Act (FCRPA) of 1988, the NPS is required to inventory and list significant caves on federal lands, and to provide management and dissemination of information about caves. Under the FCRPA and the Code of Federal Regulations Title 43—Public Lands: Interior, Part 37—Cave Management, the NPS observes all caves as significant caves and manages accordingly. More specific guidance in managing, protecting and conserving resources in national park units is available to resource managers in the Natural Resources Management Reference Manual (RM#77). Now called Director's Orders Number 77, the guidelines under RM#77 specify the policy and program directives, the authoritative legislation, methods of protection and fulfillment of legislation, as well as an explanation of the roles and responsibilities of those who are in position to manage caves and karst. The NPS' 2006 Management Policies Handbook (4.8.2.2 *Caves*) directs the NPS to manage caves for "the perpetuation of their natural, geological and ecological conditions and historical association" as well as providing resource managers with the authority to close caves to public use in order to protect cave resources and provide for human safety. The handbook also signifies the importance of karst management (4.8.1.2 *Karst*) by stating "The Service will manage karst terrain to maintain the inherent integrity of its water quality, springs flow, drainage patterns, and caves".

Other federal legislation that plays important roles in the protection and management of karst and cave resources include:

- the National Cave and Karst Research Institute Act (1998), which centralizes, fosters, and promotes the literature of the science of speleology. It justifies and fulfills the need to centralize management and science surrounding caves and karst management.

- the Lechuguilla Cave Protection Act (1993), which symbolizes the importance and needs to management across agency boundaries and management missions when considering cave and karst protection.

- the Archeological Resources Protection Act (1979), whose purpose is the protection of archeological resources on public and Indian lands.

- the Endangered Species Act (1973), whose purpose primarily protects habitat and species who have been "listed" by said act due to population decline and promotes their recovery (preceded by the Endangered Species Preservation Act [1966]).

- the National Environmental Policy Act (1969), which declares policy to encourage and foster harmony between man and his environment including the health of the biosphere, natural resources, and the Nation.

- the Antiquities Act (1906), which protects historic and prehistoric ruins, monuments, or object of antiquity from excavation, destruction or irreversible damage on lands govern by the U.S. Government.

- the Clean Water Act (1977), which placed regulatory provisions on the discharge of surface wastewater and pollutants into navigable waters.

- the Freedom of Information Act (1966), which provides information to the public—exceptions such as cave locations have been omitted from FOIA.

- the National Park Service Organic Act (1916), which establishes unified management of NPS lands and provides a foundation of management.

- the National Parks Omnibus Management Act (1998), which defines the need for enhanced management, protection of resources, the support of scientific study, and documentation of resource conditions.

A few NPS units who have successfully employed management plans specific to cave and/or karst resources and have affected the direction of this management plan are:

- Carlsbad Caverns National Park's *Cave and Karst Management Plan Environmental Assessment*, 2006.
- Cumberland Gap National Historic Park's *Cave Management Plan for Cudjo's Cavern,* 1998.
- Grand Canyon National Park's *Cave, Karst and Mine Management Plan*, 2007
- Jewel Cave National Monument's *Cave and Karst Management Plan Environmental Assessment*, 2007.
- Sequoia and Kings Canyon National Park's *Cave Management Plan*, 1998.
- Timpanogos Cave National Monument's *Cave Resource Management Plan*, 1993.
- Wind Cave National Park's Cave and Karst Resource Management Plan, 2007.

Interagency Cooperation and Cooperative Agreements

The National Park Service has many formal Memoranda of Understanding (MOUs) and cooperative agreements related to research, management and protection of caves and karst resources.

Federal agencies

In 2003, the National Park Service became part of a collective of federal agencies in a cooperative agreement designed to identify areas of mutual concern and explore collaborative efforts in research, management and protection of caves and karst resources. Under the cooperative action known as the "*Interagency Agreement for Collaboration and Coordination in Cave and Karst Resource Management*", the Department of the Interior, Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), National Park Service (NPS), and the Department of Agriculture, Forest Service (USFS) intend to achieve more effective and efficient management of caves and karst resources. This agreement defines the authority and policies of each cooperating agency in regards to caves and karst resources, and identifies specific areas of cooperation in cave and karst management and resource protection (BLM Website/Interagency Agreement 2011).

Universities

Nationwide, the National Park Service has MOUs with several universities (e.g., Western Kentucky University and New Mexico Tech) to promote cave and karst research and protection.

Cave Conservation and Research Organizations

The National Park Service currently has a Memorandum of Understanding (MOU) with cave conservation and research organizations, such as the National Speleological Society (NSS), American Cave Conservation Association, (ACCA) and the Cave Research Foundation (CRF). Other conservation organizations with an interest in cave conservation and research, such as Bat Conservation International (BCI), also have MOUs with the NPS.

Purpose and Need for Management Plan

Caves and karst areas of the Great Smoky Mountains National Park are a small but significant resource, and exemplify the purpose for the establishment of the national park. Park caves and karst areas exhibit significant biological diversity, both subterranean and epigean in nature. Park caves are home to rare and endemic species and provide habitat for federally listed threatened and endangered species including the Indiana Bat (*Myotis Sodalis*). Several park caves have been identified to have cultural significance, including pre-historic and historic associations with native and mountain cultures.

The aesthetics and biological diversity of karst areas in the park attract many visitors. For example, Cades Cove, with over two million visitors a year, is a significant karst area. It's developed loop road and trail heads as well as historic structures and wildlife viewing make it one of the primary destinations within the park. Wildflower diversity in karst areas in the park, such as White Oak Sink, makes for popular off trail destinations. In addition, park caves exhibit extensive vertical relief due to their associated geology and hydrology, and possess rare subterranean fauna which make them attractive to recreational cavers and scientists. Ecologically, karst areas of GRSM have diverse biota often completely different than areas of GRSM with non-carbonate basement rock. Species diversity of epigean (above ground) GRSM karst terrain is suggested to be higher than non-karst terrain, exemplifying the need for focused research and management efforts in karst areas.

Protection at the level afforded to caves and karst areas by the National Park Service is unique for this habitat, although continued research and management support is needed to ensure protection is maintained at a level suitable to sustain the integrity of cave and karst habitats within the park boundary. Implementation of a Cave and Karst Management Plan will allow for consistent, informed decision-making and comprehensive management of cave and karst resources in the park.

GRSM Cave and Karst Resource Management Objectives

Based on the mission of the National Park Service, the Federal Cave and Karst Resources Protection Act, other federal legislation, and NPS guidance (CFR Title 43 Part 37 and RM#77); Cave and Karst Resource Management Objectives for Great Smoky Mountains National Park are as follows:

1. Protect and perpetuate the natural cave, karst and hydrological systems that exist in Great Smoky Mountains National Park.

2. Protect and preserve the cultural and historic resources of the caves and karst areas in Great Smoky Mountains National Park.

3. Provide for opportunities for scientific study as well as educational and recreational opportunities where appropriate.

4. Establish and maintain cooperative relationships to encourage scientific study,

research and cartographic survey and inventory of cave and karst resources and systems of Great Smoky Mountains National Park.

5. Monitoring of natural environmental conditions and visitor use and impact to caves and karst areas in Great Smoky Mountains National Park.

6. Establishment of regulations, guidelines and permitting procedures that ensure protection of cave and karst resources in Great Smoky Mountains National Park.

Known GRSM Cave and Karst Resources

Caves and karst landscapes of the Great Smoky Mountains National Park form in fensters of calcium carbonate in the Great Smoky Mountain thrust sheet. The older metamorphic rocks that make up the Great Smoky Mountains (Ocoee Supergroup: Snowbird Group-Metcalf phylite and Great Smoky Group-Cades sandstone) were thrust over much younger limestone and dolostone (dolomitic limestone) along the Great Smokies Fault (Wilson 1935; Neuman 1947; King 1968; Southworth et al. 2000). Erosion of the metamorphic rock (also referred to as nappe due to its tectonic movement over younger rock) exposed the underlying limestone and dolostone, forming the aforementioned fensters, which in turn eroded into the flat, grassy valleys typical of the Valley and Ridge Provinces of the Appalachians. It is in the lower walls and floors of these valleys and fensters where karst topography and their caves have formed (Barr 1968; GRSM 1989).

Caves and karst topography in the Great Smoky Mountains National Park have formed in Upper Cambrian and Lower Ordovician limestones in the western portion of the Tennessee side of the park (Southworth et al. 2003). This limestone (also including the dolostone portions) is known as the Jonesboro limestone (Lower Ordivician) or Shady dolomite (Upper Cambrian) of the upper Knox group (Paleozoic, 500-450 million years ago). The Jonesboro limestone is predominantly a fine-grained limestone with 0.1-1 meter thick beds. The Jonesboro is also described as having lesser areas of massive bedding containing quartz sand grains, fossils, and dolomite with calcite stringers (Southworth et al. 2005). Locally, in the Smokies, it is massively bedded and brecciated Mascot dolostone of the Kingsport (Mascot-Kingsport) formation (Haygood 1969).

Shady dolomite is localized north west of the main portion of the GRSM around Walland, Tennessee and the lowlands of the western portion of the Foothills Parkway System. As described by Nelson in “The Resources of Tennessee” (1918), Shady dolomite in Tennessee is a light gray dolomite (dolomitic limestone), largely coarse and granular. Locally, Shady dolomite has thin to massive bedding with mildly tilted beds.

Cades Cove Karst Area

Of the seven karst areas, Cades Cove is typical of a fenster with steep sides and flat bottom (Figure 2.). Encompassing approximately thirteen square kilometers, Cades Cove is the largest fenster inside GRSM’s boundaries. This area receives heavy visitation throughout the year, is extensively developed, and is the location of two known caves. The etymology of Cades Cove is unknown. The name “Cades”, as a surname, shows no records for this area or this region of the U.S. (Shields 1981). From early records, references to a cave have led some to suggest that its initial name may have been “Cave Cove” instead of “Cade(s) Cove”. It is likely a question that may never be answered. Cades Cove receives over two million visitors annually, who mainly come to travel the eleven mile paved loop road to experience the wildlife and 19thcentury culture

Figure 2. Cades Cove -- Approximate exposed and shallow karst within fenster.

preserved in maintained fields and twenty-six historical structures. Cades Cove had been continuously occupied from the 1700s until 1999, when the last lifetime lease expired. Early occupation of Cades Cove exploded in the 1830s and 40s due to road development, and the development of a post office (1833-1947) eased the burden of living in what was considered a remote area of the time. The height of settlement was around 1850 with 132 families and a population just shy of 700 individuals (Dunn 1988). Currently in Cades Cove the NPS manages, in conjunction with the twenty-six historic structures, a 159 site campground, eighty-one site picnic area, three site horse camp, six residential structures accommodating twenty-four seasonal (or transient) workers, a large maintenance facility, horse concessionaire boarding facility and offices, visitor center, interpretation office building, and ranger station. In addition to structures, a several-acre settling pond has been incorporated into the main leach field operations near the entrance to the cove (western end), with an additional leach field adjacent to the visitor center at the east end of the loop road (back of the cove).

Abrams Creek (historically referred to as Cades or Cove Creek) is the primary drainage of Cades Cove and is located on the floor and runs through the middle of the fenster. Its course runs through the center of Cades Cove, across bedrock limestone, with little notable drop in elevation before contact with non-carbonate rock at the back of the cove. At this point, Abrams Creek continues its path through the park, dropping substantial elevation throughout its course before impoundment at Chilhowee Lake. Abrams Creek is the largest “limestone” stream in GRSM making it one of the most biologically productive in the park. It has a small portion that runs subterranean, which is obvious during low water when Abrams Creek appears to run dry. Many of Abrams Creek's tributaries have similar appearances running subterranean most of the year throughout the bottom of the cove (within the Jonesboro limestone and colluvium) while holding visible water where they originate on the Metcalf phyllite and Cades sandstone high in the mountains. Much, if not all, of the floor of Cades Cove is comprised of well-drained, shallow karst conduits, transporting water towards Abrams Creek. Exact flow paths and depth of karst development below the water level are unknown.

Gregorys Cave

Gregorys Cave is located along the lower reaches of Cave Ridge on the northern slope of the Cades Cove karst window at an elevation of 610 meters. Gregorys Cave is represented as the 4th discussed cave in Blount Co., TN in Barr's Caves of Tennessee (1961). Named after the Gregory Family who lived near the cave until the time the park was established, this cave was historically used as a food storage area to keep food cool in the summer and from freezing in the winter. Historically, a wooden gate prevented scavengers from entering the cave. At some point, this gate was replaced with a vertically slatted metal gate by the NPS. Gregory Cave has extensive references in pre-park files exemplifying its popularity in the Cades Cove Community. It was also one of two caves in Blount County (the other being outside the park-Tuckaleechee Caverns) identified as a "fallout shelter" (GRSM *No Date*). In the back of this cave is a suspected petroglyph of a wild turkey thought to be the only visible evidence of prehistoric use of caves in the park by Native Americans. Park archeologists, through their observations, have suggested that evidence exists showing Native American use of the entrance area of this cave due to charcoal and stone fragments in sediment layers.

The cave has 305 meters of surveyed passage with a vertical extent of six meters. The cave is essentially a borehole, paleo-trunk passage, with vaulted ceilings exhibiting heights from six to seventeen meters and widths almost twice that. There is also a low, wide side passage that extends over thirty meters (Appendix a.). The main trunk passage is arguably the most decorated of any cave in GRSM (Appendix b.). Large ceiling to floor formations with large rimstone pools are highly developed from just inside the cave to the end, with the side passage being the exception. The west side of the cave exhibits solution pockets which continue to feed calcite saturated water to the white/cream formations, while no longer active formations have retained their gray and black soot coloration from the historical use of fire in lighting the cave.

Gregorys Cave is biologically diverse, being the type-location of two obligate cave species (amphipods of the genus *Stygobromus*), one of which has been found nowhere else. It has been a choice of scientists who wish to collect and study cave dwelling organisms in GRSM due to its ease of access and diverse cave fauna. The cave is also home to over 900 hibernating bats in the winter, although until the NPS replaced the vertically-slatted gate with a bat-friendly horizontal gate in the 1990s, there was very little evidence or reporting in the literature of bat use of the cave. Well-worn paths exist from human use pre and during park management. All easy routes through the cave show extensive foot traffic and soil compaction. Cave formations have been handled if not broken off over the years, most likely when it was utilized as a community gathering location. There is no sign at the entrance of Gregorys Cave addressing entry restrictions, although a gate eight meters inside the natural opening prevents illegal entry.

Tory Shields Bluff Cave

Tory Shields Bluff Cave (also called Abrams Creek Cave in historical literature) is located within the Cades Cove karst window at an elevation of 537 meters (Appendix a.). The opening is at the base of a large limestone outcrop in a dry floodplain/stream channel just east of an old quarry in the same outcrop. The cave itself is mainly a horizontal crawl hole with several small pools of water during wet periods. There are two entrances and a small skylight. The upper entrance can be connected to the lower but is physically restrictive to most. Historical use by an American black bear (*Ursus americanus*) and raccoons (*Procyon lotor*) has been mentioned in previous descriptions of this cave. The current map shows 129 meters of passage with six meters of vertical relief. There exists additional passage that has not been surveyed.

Biological components to this cave are vague; several attempts have been made at exploration in hopes of duplicating the species diversity of nearby Gregorys Cave but the majority of the species are absent. This cave lacks the year-round epikarst drips that supply the necessary water for many of the aquatic cave species of Gregorys Cave. Additional research at varying times of year might be necessary to see if additional species use Tory Shields Bluff Cave as temporary habitat.

This cave floods readily. It appears to be an overflow conduit for tributaries of Abrams Creek and may also be a spur conduit of Abrams Creek itself. At a minimum, this caves proximity to Abrams Creek warrants safety concerns related to rising water levels during storm periods.

There is no gate to prevent entry into Tory Shields Bluff Cave, although a nearly illegible and uprooted sign alerts the visitor to the presence of an otherwise obscure cave entrance. The sign warns the visitor that a permit is required to enter the cave.

Rich Mountain Karst Area

The Rich Mountain karst area is an approximately 0.37 square kilometer uvala (Bull Cave Sink) of the greater Tuckaleechee Cove fenster, which is outside of the park (Figure 3).

Figure 3. Bull Sink, Rich Mtn. – Highly developed portion of Tuckaleechee fenster just inside of NPS (green) boundary.

The sink measures approximately 610 x 610 meters at its widest points on the south slope of Rich Mountain. The base of the sink drains into the Historic entrance of the Bull Cave System, one of six caves with entrances in the sink. This area is easily accessible, and also the home to two of the deepest caves in the eastern United States.

The epigean environment of Bull Sink is unique, containing two rare species of liverwort, one known from no other locations with closest relatives in the Himalayan Mountains (DLIA website 2008). Rich Mountain Road, a one-way exit route out of Cades Cove dating back to the mid 1800s, exits the park after a short traverse of the sink. Historic use of the area is not well known. Records suggest that logging of the area left no tree standing and reports state slash was dumped into the sink from both the road and the slopes of the sink. Additional accounts of the area after logging state that the cave was at time "inaccessible due to an entrance plugged with cut trees, mud, and water" (GRSM *No Date*). Terminal hydrology of this area is unknown and needs to be dye traced to confirm its destination. All caves on Rich Mountain likely resurge at Short Creek prior to flowing into Little River near Kinzel Springs, Tennessee.

Bull Cave System (Historic Bull and Snakedance Entrances)

The Bull Cave System is the deepest known cave in GRSM (as well as Tennessee) at 282 meters. It is ranked as the third deepest in the eastern U.S. and the twentieth overall in the U.S. Bull Cave has two entrances, the historic entrance and the more recently discovered Snakedance entrance. The total mapped length of cave is 3656.4 meters. It trends north and terminates outside of the park boundary at a low water sump (Appendix a.).

The historic entrance of Bull Cave resides in the drain of a large sink (known as Bull Sink) on the south side of Rich Mountain just within the boundary of GRSM at an elevation of 561 meters. A short and well-worn trail leaves the parking lot at a well known trailhead down into the sink and to the entrance of Bull Cave. The sink and cave continually take water from a small surface stream that can be followed through most of the historical side of the cave. The historical descent into Bull Cave requires descending three vertical drops of 12.2, 51.5, and 27.1 meters as well as some exposed down-climbs in often cold and wet conditions. The temperature of the water entering the cave strongly influences the temperature of the cave. At the historical terminus of the cave is a shallow sediment plug which, when crawlable, leads to the remainder of the stream passage and connection with the Snakedance side of the cave.

The Snakedance entrance is much higher above the historic entrance to the cave, on the south flank of Rich Mountain at an elevation of 634 meters. The entrance is at the bottom of a steeply sided sink within the confines of the larger Bull Sink. This entrance is a vertical drop of twelve and a half meters followed by thirteen nearly continual drops ranging from three to forty-four meters to the Bull Cave stream passage and sump.

The historic entrance to Bull Cave leads to a significant Indiana bat (*Myotis sodalis*) hibernaculum, and has other cave species endemic to the park. The vertical extent of this cave system and possibilities for more discoveries in it make it one of the most desirable caves to recreation and exploration cavers.

The cave is mainly linear and confined to a small stream passage, which plunges into tall rooms with occasional sediment mounds. Use over many years has caused trail compaction in many of the rooms along the historic side of the cave--mainly David's Room. The Snakedance side of the cave is similar, with the majority of human sign being focused along the drainage path and erased with significant rain events. In the larger rooms of the cave, trails appear to be consolidated to natural routes leading deeper into the cave. There is currently no sign at either entrance (historic Bull Cave or Snakedance) warning against illegal entry.

Rich Mountain Blowhole

Rich Mountain Blowhole [Cave] begins high along the south slope of Rich Mountain in a shallow sink at the head of a dry valley within the larger Bull Sink at 622 meters. The entrance to the cave was illegally dug open and currently has a locked, air-restricting gate and entrance culvert to mimic pre-digging environmental conditions. This solid, ground-level, horizontal gate is often obscured by leaf litter, and there is no sign warning against illegal entry. The illegal alteration of material to gain access to this cave has been the center of much controversy between cavers seeking access to continue exploration of GRSM caves and NPS' hesitance to trust some cavers with these resources. Rich Mountain Blowhole is the second deepest cave in Tennessee (and GRSM) at 256 vertical meters (Appendix a.). It ranks nationally one place behind the Bull Cave System at the fourth deepest for the eastern U.S. and twenty-fifth across the U.S. Right or wrong, the discovery of this cave was and is paramount to understanding GRSM caves and karst hydrology as well as how to manage them.

Rich Mountain Blowhole continues to blow air out of nearby rock piles too small to enter; the dug entrance contains ten vertical drops that require rope to descend. It is similar to the Bull Cave System in that it follows a series of highly vertical bedding planes until it reaches the water table where it begins a long horizontal path north exiting the park. It also contains several domes that have been explored and added to the overall length of the cave. Much of the human traffic throughout the cave has left negligible damage to the condition of the cave. It is noticeable that the cave has seen visitation but compared to the Historic entrance to Bull Cave, it is minimal.

Rich Mountain Blowhole, like the Bull Cave System, has extensive vertical relief and possibilities for more discoveries that make it another desirable cave to recreational and exploration cavers.

Calf Cave I

Calf Cave I is located just inside the GRSM boundary on the periphery of Bull Sink at an elevation of 579 meters. This cave and nearby Calf Cave II are at the bottom of a small sink, six by eleven meters at its widest, along the trail to Bull Cave. The sign at the rim of this sink alerting visitors to the need for a permit to enter either cave has been recently stolen-2008.

Calf Cave I is predominantly horizontal with a small stream passage trending towards the historic entrance of Bull Cave (Appendix a.). This passage contains fifty-three meters of mapped passage with two high ceiling rooms inside the entrance adding to the mapped eighteen meters of vertical relief (Matthews 1971). This cave has seen much visitation over the years resulting in accumulated trash in the main entry room. Most of the passage has been explored by cavers and surveyed.

Calf Cave II

Calf Cave II is at the bottom of the same sink as Calf Cave I. The cave is short at seventeen meters with well over the Tennessee Cave Surveys listed three and a half meters of vertical relief. Just inside the entrance is a four and a half meter vertical pit. The small stream passage trends in the same direction as Calf Cave I towards the historic entrance of Bull Cave (Matthews 1971). This cave has been a natural trap for trash thrown into the Calf Cave(s) sinkhole. The cave itself appears to have had little visitation, likely due to the entrance pit. Most of the passage has been explored and surveyed by cavers.

Hidden Hole Cave

Hidden Hole cave was initially mapped in 1998 to a length of approximately thirty meters and a vertical relief of approximately nineteen meters, although the cave has been known for many years by Rich Mountain cavers. The cave is in a dry valley of the Bull Cave Sink at an elevation of 600 meters. The entrance is a vertical collapse in unconsolidated limestone rubble requiring rope to enter. The remainder of the cave mimics the entrance and is a collapsing vertical shaft broken with debris plugs. Its unstable entrance is very dangerous and it is difficult to avoid partial collapse during exploration. Due to the nature of its instability it is possible that at any time, additional passage will be revealed extending its length and depth and conceivably allowing additional access into either the Bull Cave System or Rich Mountain Blowhole (GRSM 1998).

Biology of this cave is unknown. Bats have been observed using it in summer and winter months though numbers are low. There is currently no sign to warn visitors against illegal entry into this cave.

Big Spring Cove Karst Area

An earlier stage of a karst window exists in the Big Spring Cove area (Figure 4.). This area is typified by several sinkholes (< 9 meters in diameter) in Metcalf phyllite that do

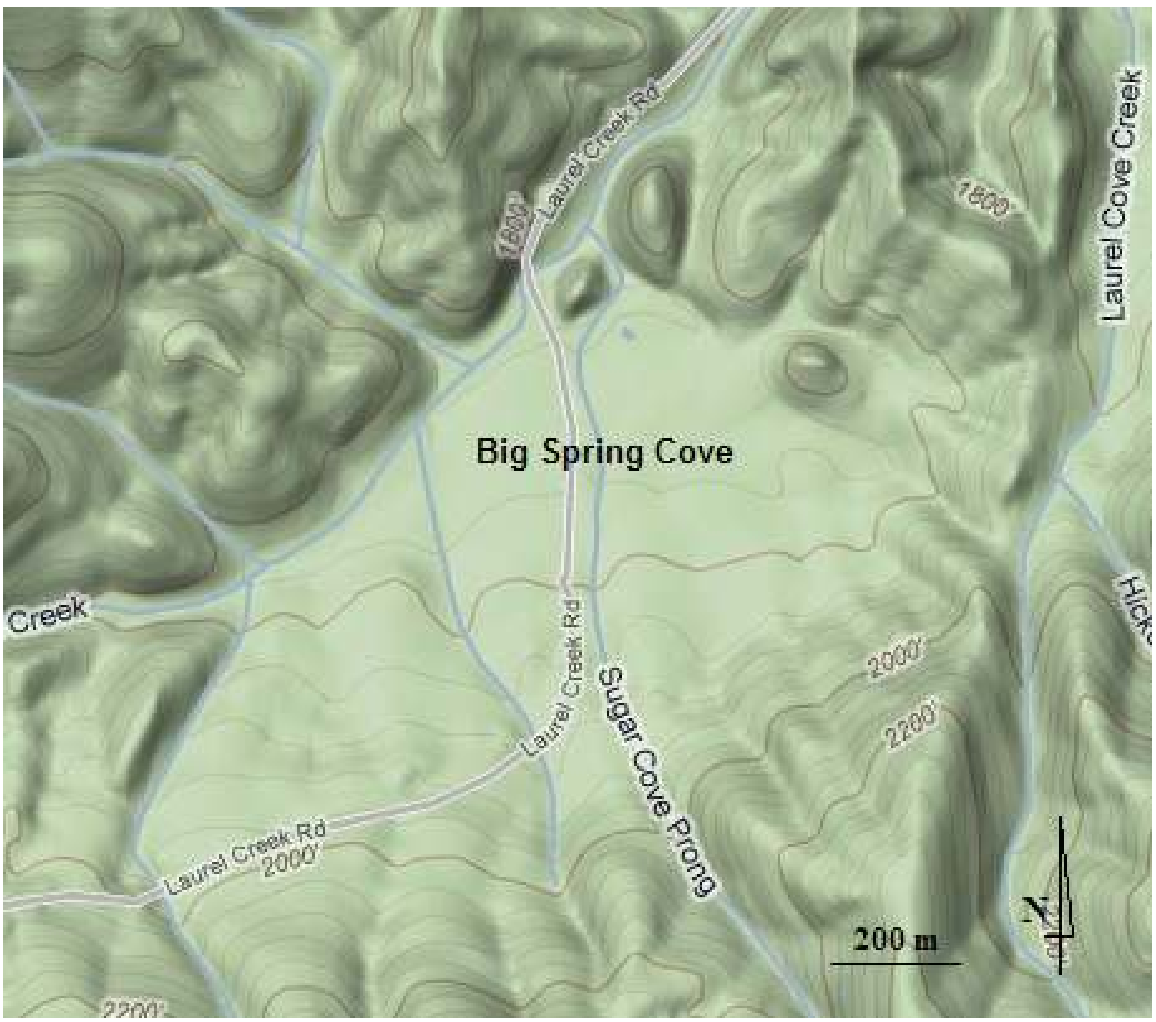

Figure 4. Big Spring Cove–Example of developing fenster. No surficial carbonate rock.

not permit quick drainage of surface water into the underlying Jonesboro limestone. During wet periods, these sinks hold water and are important ecologically to such organisms as amphibians. Test drilling was done in 1951 to determine the depth at which carbonates existed below the surface. Carbonate rock was encountered at fifteen meters below the surface (King 1964). The existence of sinks show that karst in this area is active but remains covered by weather resistant non-carbonate rocks of the Ocoee Supergroup. Geographic observation based on the leveling of topography suggests that this active karst area is approximately 0.56 square kilometers. Surface biology mimics surrounding areas of non-karst with the exception of these seasonal pools. Karst drainage is likely into the neighboring Laurel Creek/Little River drainage. There are no known caves in this area (Southworth et al. 2005).

Historic use of Big Spring Cove is evident in the altered topography of the cove. One of the sinks has been breached manually to drain water, possibly for farming. Due to the level topography of the cove, small-scale farming was the primary use by homesteaders in this area, and remnants of a few homesites still remain. The proximity of Big Spring Cove to Cades Cove, as well as being on the main route to Cades Cove during the mid- to late-1800s has added to the historic and current land use of the area.

Today the area has been allowed to regenerate to a mature secondary forest. The historic trials and roads leading to long abandoned home sites have been turned into trails and trailheads by the NPS and receive visitor use equivalent to other areas of GRSM. Laurel Creek Road, the primary road into and out of the Cades Cove area of the park, bisects Big Spring Cove (Figure 4).

White Oak Sink Karst Area

White Oak Sink karst area is also on the periphery of the Tuckaleechee Cove fenster and encompasses about 11.2 square kilometers. White Oak Sink is a very large uvala whose karst is continuous with that of the Tuckaleechee window but is isolated somewhat by the elevation differences (Figure 5). The NPS does not maintain trails into or within White Oak Sink but an elaborate set of man-ways (unmaintained social trails) lead to many of the “desirable” features of the sink including caves, a cemetery, various wildflower ecotones, and historic homesites. On the floor of the sink are two of the seven caves that have openings within the sink's elevated rim. White Oak Sink is likely the most popular off-trail hike in GRSM. The wildflower diversity has caused visitation in the spring to reach unmanageable levels at the primary trail-head and year-round use has continued to increase.

Current access to the sink is by two primary locations. School House Gap trailhead, on Laurel Creek Road, allows access to School House Gap Trail and ultimately the main (southern) man-way accessing White Oak Sink. This route is approximately four kilometers one way to the bottom of the sink with half that distance on unmaintained trails. The other route into the sink follows the historic route into White Oak Sink and beyond to Cades Cove. School House Gap trail was the former road into Cades Cove around 1850. It was known as the McCampbell-Anderson Turnpike or road (Shields 1981). This road began in Dry Valley, a portion of Tuckaleechee Cove, and entered what would become GRSM at School House Gap. This road continued to what is now Laurel Creek road and via Crib Gap, enters Cades Cove. At School House Gap, the historic

Figure 5. White Oak Sink. -- Highly developed portion of Tuckaleechee fenster just inside of NPS (green) boundary.

route into White Oak Sink veered west along a low-gradient stream, then through a shallow gap into White Oak Sink. At this shallow gap, the old access route leaves the metamorphic walls of the sink and enters the karst topography of White Oak Sink. Shortly below the gap at a junction with a larger dry valley the road passes Saltpeter Cave before reaching the bottom of the sink. Today, access to School House Gap and the park boundary from the north requires hiking close to a kilometer on private property. At the gap this route is overgrown, but the old road-bed is easily followed and allows for an alternate route into the area.

Historic land use was similar to Cades Cove; small-scale farming and limited livestock grazing in the bottom of the sink were the primary land uses of four families who resided there. After incorporation into GRSM, White Oak Sink was allowed to succeed into the closed canopy, secondary forest of today (Jenkins et al. 2007).

Recently (2009), the NPS has installed a horse barrier at the entrance to the southern man-way from the School House Gap trail. In addition, "No Horses" signs were installed at both man-way entrances, and a sign at the edge of the main sink area suggests hikers stay on trails to reduce impact to the sensitive area.

White Oak Blowhole Cave

White Oak Blowhole Cave is located in the northeastern "corner" of White Oak Sink at an elevation of 500 meters. The entrance is obvious due to the large bat-friendly gate that protrudes like a box in front of a steep limestone bluff (Appendix b.). Behind the gate is a short climb down into the entrance room. In the floor of the entrance room is a triangular shaped opening that descends vertically just over nine meters into an elevated alcove of a much larger room. This room is estimated at twenty-three meters wide by ninety-one meters long and nine meters high. The floor is scattered with large breakdown rock from the ceiling. Two large leaching areas are observable from past efforts of guano mining and saltpeter extraction. The cave has a surveyed vertical extent of 134 meters and a length of 1856 meters (Appendix a.).

The main extent of the cave is this large main room which trends downslope towards a terminal sump that has been dove to twenty-five meters. The water in this sump is beautifully blue and at times has many contrasting orange spring salamanders (*Gyrinophilus porphyriticus*) and red black-chinned red salamanders (*Pseudotriton ruber*). A northwest passage continues for 121 meters from the entrance drop to a well-decorated room known as the "torch stick room". This portion of the cave is one of the primary winter roosts for Indiana bats (*M. sodalis*) and has seen extensive mining of guano for saltpeter extraction. The name "torch stick room" is given due to the numerous cedar torch stick fragments left behind by miners. Tally marks are also evident in the torch stick room as well as other portions of the cave as a reminder of the mining that has taken place.

This cave is Tennessee's largest know Indiana bat hibernaculum, with counts numbering close to nine-thousand at their peak. Two additional species of bats are also prolific in the cave and together could account for close to 12,000 bats. Additional cave biota is common of the species typical for GRSM caves but can be difficult to find due to the expansive nature of the main room in this cave.

Although an interpretive sign exists on the gate explaining the importance of protecting bat hibernacula sites, the NPS sign directing visitors to obtain a permit for entry to the cave has been dropped down the entrance pit beyond the gate, and now rests in the main entry room of the cave.

Rainbow Cave

Rainbow Cave, sometimes called Rainbow Falls Cave, is located on the southeastern corner of White Oak Sink at an elevation of 512 meters. The entrance to the cave is at the base of a waterfall that drops nine meters after reaching soluble limestone at the Great Smokies Fault (Appendix b.). The Great Smokies Fault is clearly observable at the contact between the lower limestone beds and the upper weather resistant metamorphic rock of the Ocoee Supergroup. There are at least two entrances into the cave at the base of the falls (Appendix a.). One is a climbable pit that corkscrews for three meters before entering a room under the breakdown pile below the falls. In this room, water from the falls percolates through the ceiling making it impossible to stay dry. Following the flow of the water, you enter a tight wet crawl that, depending on water level, may not be safely passable. Beyond this constriction is a small dome room with a side passage entering from the other entrance and a hands-and-knees crawlway in which the water follows. The second entrance is tight at the base of the falls but opens to follow an overflow channel of washed dolostone with calcite stringers for forty-six meters where a four meter high climb down meets the other entrance route in the small dome room. The hands-and-knees crawlway that ensues for thirty-seven meters to the first nine meter drop. The drop is bolted with a single hanger and can be backed up off natural anchors. The descent is wet and at the bottom, after a short ten meters of passage is another nine meter drop, bolted again in continuous water. The Knoxville Volunteer Emergency Rescue Squad (KVERS) placed both bolts in February 2008 during the rescue of four young adults who became trapped and hypothermic during a late night, unpermitted trip into the cave. The terminal siphon is in a short down climb in the main room at the bottom of the cave. The room is spacious, ranging larger than nine meters wide by over thirty meters long. From the siphon the room continues up over breakdown into a lofted area with one possible high passage lead.

This cave has the potential to be very dangerous during periods of rain. Flash flooding could easily trap people inside the cave as well as make either of the two waterfall climbs very difficult. Species diversity is similar to other caves of the area. 2009-2011 bat hibernacula surveys found Indiana (*M. sodalis*) and Little Brown (*M. lucifuga*) bats as well as Tri-colored (*Perimyotis subflavus*) bats present. Currently, there is no sign to warn visitors against illegal entry to this cave.

White Oak Saltpeter Cave

White Oak Saltpeter Cave is located at an elevation of 549 meters in a small sink, eight meters in diameter, upslope of the bottom of White Oak Sink in an unnamed dry drainage in the direction of School House Gap. It is adjacent to the historic trail (road) that accesses White Oak Sink from School House Gap. The name of the cave is a misnomer; there is no evidence that any saltpeter mining has occurred in this cave. It is also unlikely that there was or would ever be a reason to mine this cave. The cave is small and does not possess guano piles sufficient for extraction. It is likely that the neighboring cave, White

Oak Blowhole, was likely called “Saltpeter Cave” at one time due to its extensive sign of nitrate removal efforts. Some confusion in nomenclature can be speculated which has caused the name to be associated with this cave instead of the other likely choice.

This cave is relatively small compared to the neighboring White Oak Blowhole and Rainbow Cave. It has forty-nine meters of surveyed passage with a vertical extent of six meters. The cave has a large entrance room with two small domes on its north margin. It receives water from a small fissure that quickly disappears into a hole in the floor that could possibly be explored by somebody small. The main room funnels into a small crawlway with water draining from the back of the cave. This water disappears through a tight constriction in the floor that immediately opens into what looks like a possible lead. Beyond the drain in the floor, the cave opens back up into a series of short upper passage sections connected to the small stream passage before the source of the stream is reached at a spring-like area in the back of the cave. There are two very small leads off the southeast side of the cave but both are too tight for most to enter. At least one of these exhibits significant air movement, suggesting additional passage or a more likely connection to White Oak Blowhole Cave.

This cave seems to receive a fair amount of illegal visitation that has resulted in several names/initials written in mud along the far reaches of the cave. Most of the dates are within the past fifteen years with several new additions identified with each NPS visit. A barely legible sign is propped up against the entrance to the cave, warning visitors against illegal entry (Appendix b.)

Scott Gap Cave

Scott Gap Cave is in a large sink in the northwest portion of the much larger White Oak Sink at an elevation of 555 meters. The entrance to the cave is under a large exposed portion of Jonesboro limestone at the base of the sink, which on occasion fills with organic debris. Directly inside the opening is a vertical entrance drop of eleven meters into the cave. A tilting passage approximately eight meters high by equal distance wide, following the dip of the beds, proceeds down slope while a much smaller passage runs upslope for short distance before terminating at a four meter dome. The majority of the cave down slope is a series of easy climb downs to a constriction at the second drop of twelve meters. At the bottom of this drop, a small tight stream passage drains the small room with an eleven meter ceiling. The low stream passage winds north for a hundred feet before it becomes too tight to proceed.

This cave has been observed to house 200 or more Indiana bats (*M. sodalis*) during the winter though recent numbers are much lower. In addition, the small pool of water in the bottom of the second drop contains many of the aquatic cave organisms found in other GRSM caves with stationary water. A sign at the rim of the sinkhole warns visitors against illegal entry and the need for a permit to enter the cave (Appendix b.).

Scott Mountain Cave

Scott Mountain Cave is a very short solution feature high on Scott Mountain at an elevation of 683 meters. It is within the confinement of White Oak Sink on its northwestern slope, and the entrance is a small inconspicuous hole that covers with leaf litter every fall. The cave is short, about nine meters, with a sloping portion just inside the entrance suggesting subsidence. The ceiling is low and only the entrance area permits standing. The back of the cave doesn't seem to warrant further attention.

Interestingly, the cave always seems to contain fresh Allegheny Woodrat (*Neotoma magister*) nesting material (fresh vegetation and leaf litter) as well as a very large population of the spider *Meta ovalis*. No biological inventory has been done outside of the author's observations. No sign exists that warns visitors against illegal entry, or the presence of a cave. Little human sign suggests entry is not taking place at a level high enough to warrant concern.

Sinking Stream Cave

Sinking Stream Cave is another small cave within White Oak Sink. Its opening is at the bottom of a deep sinkhole at the foot of a small stream at an elevation of 555 meters. The sinkhole is collapsing, and trees are occasionally uprooted along its rim and sediment is continually drawn into the entrance to the cave. The stream disappears prior to the sinkhole except during periods of extensive rain. The cave is unmapped and on occasion seems to blow a slight amount of air. It is possible that it is hydroligically connected to White Oak Blowhole.

The cave is nothing more than a mud filled, and occasionally plugged entrance that leads three meters to a short climb down of twenty feet. Water enters through breakdown into the small pit and quickly disappears into the coarse floor medium. Old pottery fragments and man-made materials from pre-park homesteading were found within the cave pit suggesting the sinkhole has been used as a trash dump previously. No biological inventory has been done outside of the author's observations. There is currently no sign warning visitors against illegal entry, or alerting visitors to the presence of a cave. Some human activity has been observed at the entrance.

Pie Hole Cave

Pie Hole Cave is located less than ninety meters from Sinking Stream Cave on the western slope of White Oak Sink at an elevation of 549 meters. The cave is inconspicuous except for the large sinkhole it is in. It appears that the sinkhole has been used as a repository for field rock during the settlement period as one side of the sink is awkwardly man made with loose chunks of limestone. The cave is hidden among tall vegetation during summer months but visible during winter. The cave itself is small, less than ten meters. It corkscrews down into a muddy, rocky sink with large bedrock along one wall. Between two large pieces of limestone is a fissure with substantial air and a faint gurgle of water. This is likely the water from Sinking Stream Cave. It seems possible if not likely that this water continues towards White Oak Blowhole Cave and resurfaces along the northwest passage of that cave.

Pie Hole Cave gets its name from the shape of the opening that looks like a mouth. Also notable is the use of this cave by bats at several times of the year. No biological inventory has been done outside of the author's observations. No sign exists that warns against illegal entry to this cave, or alerting visitors to its presence. Little or no human sign has been observed in or near the cave.

Calderwood Karst Area

The Calderwood karst area lies just below Calderwood dam on the Little Tennessee River. There are several known caves in this karst unit based on the 2009 TCS database. GRSM, in 2009, acquired land above this karst area but investigations have been unable to determine if any of the karst area is currently under GRSM management. The land is adjacent to property owned and maintained by Topoco, a subsidiary of Aluminum Company of America (Alcoa), as the Calderwood Hydroelectric Development Area. It appears unlikely that surficial karst exists within the boundary of this newly acquired property. However, further investigation is needed to determine if any of these karst systems originate within this extended boundary of GRSM and what type of management, if any, is necessary.

At this point it seems to suggest that the area known as "The Bulge" has the best possibilities as some of its south and western perimeter will adjoin known karst areas in the Calderwood karst area. However, Topoco's choice to retain the lower, flat topography of the area will omit much of the highly karstified bedrock. Caves on Topoco's property adjacent to The Bulge suggest at least some subterranean flow which has possible origins higher up slope in GRSM managed land. Field observations do not show any distinct subterranean input of water into the non carbonate areas within GRSM's management area.

Foothills Parkway (Walland, Wear Cove, Cosby, and Pigeon River) Karst Areas

The Great Smoky Mountains National Park manages a narrow strip of land around the Tennessee side of the park designated as the Foothills Parkway System. Not all of the parkway is complete at this time. The geology of the parkway is consistent with the Smokies where older metamorphic rock is located at higher elevations and younger carbonates are found beneath, exposed at lower elevations. This corridor crosses several large karst windows; two caves are known from this right of way, one in the Walland karst area (Shady dolomite) and one in the Wears Cove fenster (Jonesboro limestone). Karst along the Foothills Parkway System is minimal, occurring often at parkway junctions at lower elevations. Common features are large sinkholes and limestone bluffs. Actual size of karst areas of the parkway is unknown.

Stupkas (Myhr) Cave

This cave is named both Stupkas (GRSM's first naturalist) and Myhr (adjacent landowner) in literature but exists as Stupkas Cave in the Tennessee Cave Survey (TCS) records. Stupkas Cave is 213 meters long with fifteen meters of vertical extent. The cave is mainly a tight, wet, and winding stream channel, the entrance being a collapse adjacent to the resurgence spring. The spring is on adjacent property and feeds a large pond owned by the Myhrs and is also their main source of water.

The cave is developed at the base of the south slope of the Wear Cove fenster at an elevation of 466 meters. Development above this cave and the Foothills Parkway System is thought to be the source of seasonal turbidity of the Myhrs' water source in the past ten years.

Cave biota in this cave is similar to other GRSM caves but also possesses the type-location of an endemic spider (troglophile) of the genus *Nesticus* exemplifying the importance of protection. According to bat surveys, bat diversity in this cave seems to be high, although records indicate population numbers of many species are relatively low. There is currently no visible sign warning against illegal entry.

Foothills Parkway Cave at Walland

The Foothills Parkway Cave at Walland has developed in a fissure in the Shady dolomite of the Knox Group at an elevation of 305 meters. It is on a limestone bluff high above Little River on a narrow strip of the Foothills Parkway System. The vertical extent is enough to warrant the use of a rope to access.

The cave is a vertical fissure of approximately six meters deep with less than four meters of traversable passage at the bottom. It does show sign of carbonate dissolution within the cave and bats are known to hibernate under several small shelves along the bottom of this cave. No biological inventory has been done outside of the author's observations. There is currently no sign warning against illegal entry or alerting visitors to the presence of the cave. No human activity has been observed in the cave.

Foothills Parkway-Interstate 40

In the far Northeastern corner of the park, as part of the Foothills Parkway East, is a low lying karst area adjacent to the Little Pigeon River in Cocke Co., TN. The area needs further delineation as to its exact size but field observations show karstification taking place on both sides of Interstate 40 at the junction of the Foothills Parkway East's eastern terminal. The area furthest east adjoins the Little Pigeon River where limestone is obvious along the river incision and flood plane. No cave development is observable though dissolution of limestone is apparent along rock outcrops. It appears that the karst area continues under Interstate 40 to the western portion of the terminus of the Foothills Parkway East. At this location, it appears that the carbonate rocks are covered with non-carbonates. No limestone was found. Active karst development is seen as large shallow sinks on what looks to be an old river terrace higher up on the mountain.

Little information exists in park literature on the area. General geology of the karst bedrock appears to be consistent with other park carbonates. Cambrian- Ordovician limestones (Jonesboro Limestone) would be the predominate karstified rock. Further interpretation of the rock itself might yield more detail to its origin or similarities to Blount or Sevier Co. limestones.

No hydrology has been observed in this area outside of the surficial Little Pigeon River.

Foothills Parkway-Cosby

Little is known about the karst areas around the junction of the foothills parkway and US route 321 (SR 32, 73). In looking at aerial photos, topographic maps, and park boundary maps I can conclude that some karst is managed by GRSM in that area. The expansion of kudzu on adjacent lands makes surficial observations nearly impossible. The lack of park boundary signage as well as private property made attempts at defining the boundary somewhat difficult. At a minimum, karst is present at the lowest areas along Cosby Creek. I have had reputable reports from cave explorers and naturalists that carbonate bedrock exists higher up on the flanks of Webb Mountain but access has been difficult and the location not documented. Topography in that area does not suggest that those areas contain highly developed karst terrain or if they do, fall under management of

GRSM.

The only observed hydrology is that of surficial Cosby Creek, the main drainage of the valley in this area.

History of Cave and Karst Management in Great Smoky Mountains National Park

Management

Historically, management of karst resources in Great Smoky Mountains National Park was not based on an approved management plan for caves and karst. Two draft management plans for caves were developed, but their implementation was limited due to their lack of accuracy and completion. In 1979, the first attempt at developing and implementing a cave management plan was alternately named "Indiana Bat Management Plan" and limitedly focused on resources other than the Indiana bat. Following the development and inception of the FCRPA in 1988, GRSM developed another draft management plan (1989) that incorporated additional resources but was never completed or implemented. Management decisions in regards to cave and karst resources followed general directives and the park's Superintendent's Compendium. Signs alerting visitors that permits are required to enter park caves were installed in the 1980s, and bat friendly metal gates in the late 1990s on several cave openings (White Oak Blowhole and Gregorys Cave).

Biological Inventory

As early as the 1930s, park managers expressed an interest in better understanding the cave and karst areas in the park. Early efforts to describe the park's caves were focused more on the geology and physical conditions inside the caves rather than the fauna (GRSM 1936). In 1974, Great Smoky Mountains National Park began studying human impact and restricting access to park caves because of the presence of Indiana bats (*M. sodalis*), a federally protected species (GRSM 1979; Rabinowitz and Nottingham 1979). Currently, the only continuous sampling of cave biota is conducted in conjunction with the United States Fish and Wildlife Service’s Indiana bat hibernacula counts. It was not until the early 1980s when there was a concerted effort to identify and describe specific species associated with caves and karst. Beginning in 1984, under the direction of Great Smoky Mountains National Park resource managers, Richard L. Wallace completed a series of biological survey reports of the Great Smoky Mountains National Park's caves. Although there existed data on bat fauna that occurred within the park's caves, Wallace noted that knowledge of other cave fauna was “incomplete or unknown”. Wallace's biological surveys uncovered several new, rare and endemic species as well as a new location for a threatened and endangered species (Wallace 1984; 1989; 1990). Based on these findings, park resource managers began monitoring populations of cavernicoles (*Stygobromus fecundus*) in one location, Gregorys Cave (Johnson 1991). Management of Gregorys Cave was changed in order to provide protection for this endemic species. Without continued interest and direction through a cave management plan, over time, the monitoring efforts have fallen by the wayside with occasional spot checks by visiting scientists. Several independent researchers have surveyed a variety of cave and karst associated biota in the caves of Great Smoky Mountains National Park: amphibians (Dodd et al. 2001; Dodd 2003), salamanders (Taylor and Mays 2006), spiders (NPS 1992; Coyle 2006; Paquin et.al. 2009), annelids (Reeves and Reynolds 1999), and general invertebrate cavernicoles (Wallace 1984; 1989; 1990; Reeves 2000). In addition, in 2006-2007, Discover Life in America, a non-profit partner of the national park invited scientists with a specific interest in karst areas to participate in a "Karst Quest" to identify and describe both cave life and associated epigean biology related to the karst areas in the park. In 2009 GRSM acquired property along the Little Tennessee River on the western border of the park. The areas, commonly referred to as the "chocolate bar" and the "bulge", border a significant karst window referred to as the Calderwood karst window. At least two new park karst-associated species have been identified (2009) on these properties and it is likely additional new park species will follow (DLIA 2009).

Through the aforementioned inventories of cavernicoles and associated biota of the karst areas in the Great Smoky Mountains National Park, a total of eleven troglobitic organisms have been described in the caves of the park (Table 1). Of these eleven organisms, seven have been identified to species, and four to genus. These organisms include amphipods, isopods, diplurans, millipedes, flatworms and arachnids. One of the eleven organisms, an amphipod (*Stygobromus fecundus*), is endemic to one cave (Gregorys Cave). Approximately 270 organisms have been otherwise described in association with the caves and karst areas in Great Smoky Mountains National Park. Of these, over 200 organisms have been identified to genus level and 50 to family. Over fifty of these organisms have been identified as troglophiles, and 40 as trogloxenes. Countless other more commonly occurring organisms use karst habitats non-specifically.

Species	Common name	Record location (cave)	Citation
Stygobromus fecundus	amphipod	GRC	Wallace 1984, 1989; Mays 2002
Stygobromus sp. (fecundus?)	amphipod	GRC	DLIA 2008; NPS 1991; NPS 1992; NPS 1993; NPS 1994; NPS 1995; NPS 1996
Stygobromus sparsus	amphipod	GRC, SGC, SPC, RMB, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002
Litocampa sp.	dipluran	BLC, CC1, RMB, SGC, SPC, WOB	Reeves 2000; DLIA 2007
Sphalloplana sp.	flatworm	GRC, RMB	Wallace 1984, 1989; NPS 1991; NPS 1992; Reeves 2000; DLIA 2008
Caecidotea incurva	isopod	GRC, MYC, RMB, WOB	Wallace 1984, 1989; NPS 1993; Reeves 2000; Mays 2002; DLIA 2007
Caecidotea sp.	isopod	MYC	Reeves 2000
Scoterpes sp.	millipede	BLC, CC1, GRC, RMB, RBC, SGC, SPC, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002; DLIA 2007
Appoleptoneta sp.	spider	RMB	Reeves 2000
Nesticus barrowsi	spider	CC1, CC2, GRC, RBC, RMB, SGC, SPC, WOB	Wallace 1984, 1989; Reeves 2000; Mays 2002; DLIA 2007
Oreonitides Beattyi	spider	BLC, CC1,	Paquin et al 2009
Phanetta subterranea	spider	BLC, CC1, GRC, RMB, SGC	Reeves 2000; Mays 2002

Cave location codes: BLC= Bull Cave; CC1 and CC2= Calf Cave 1 and 2; GRC= Gregorys Cave; MYC= Myhr Cave; RMB= Rich Mountain Blowhole; RBC= Rainbow Falls Cave; SGC= Scott Gap Cave; SPC= Saltpeter Cave; WOB= White Oak Blowhole

Table 1. Identified and Described Troglobionts and Stygobionts of Great Smoky Mountains National Park

Physical (Geological, Hydrological and Meteorological) Inventory

Investigations of the surficial geology and geomorphological processes in Great Smoky Mountains National Park and the surrounding areas are well documented in the literature beginning in the early 1900s. “A Stratigraphic Investigation of Bull Cave” (Haygood

1969) remains the only documented geological interpretation of the sub-surface geology of any of the known caves in the park. Many of the park's larger cave systems have been mapped and the survey data and associated maps have been offered to the park. What information is available is housed by and is the property of the Tennessee Cave Survey (TCS 2011).

Little is known about hydrology of caves and karst in Great Smoky Mountains National Park. According to internal National Park Service Natural History files, prior to park establishment, an attempt was made to trace the drainage path of water from White Oak Sink, GRSM to Dunn Spring; Dry Valley, Tennessee. Sawdust was placed in one of two caves in White Oak Sink (White Oak Blowhole Cave or Rainbow Cave), and allegedly surfaced at Dunn Spring approximately 10 hours later (GRSM *No Date*). Although unconfirmed in park files or published literature, discussions with local cavers and NPS employees suggest that this identical path may have been traced with dye in more recent times. More recently, in 1990 a groundwater dye trace study along the undeveloped Foothills Parkway System and Stupkas Cave was done in conjunction with an assessment of potential impacts to water quality in a cave stream and karst hydrology on park service managed land (Beck and Herring 2001). General assumptions conclude that subterranean flow from the northern side of Cades Cove as well as the floor of the cove itself drain directly into Abrams Creek based on discharge proximity. Streams draining into and developing within caves on Rich Mountain appear to concentrate prior to resurging outside of the park at a primary spring on Short Creek down stream of Dunn Spring. Streams flowing into White Oak Sink via Rainbow Cave and Sinking Stream Cave likely converge with additional subterranean flow in or close to the sump in White Oak Blowhole Cave prior to exiting the park. Flow within Scott Gap Cave likely joins the majority of flow in White Oak Sink on its path to the main stream in Tuckaleechee Caverns, a developed cave in Dry Valley. From there the flow likely resurges from the subterranean environment at Dunn Springs, where it provides water for a trout farm before providing substantial flow to Short Creek. Short Creek flows out of Dry valley, TN and into Little River at Kinzel Springs, TN.

Scientifically, there has been little analysis of the meteorological conditions within park caves. It is likely that cave entrances and passages that have been altered by human processes (e.g., saltpeter extraction) may exhibit unnatural airflow characteristics that would be difficult to restore. Experienced cavers suggest that caves with extensive passages and vertical relief in the Smokies tend to be cooler year round than other caves in the region with the exception of White Oak Blowhole. White Oak Blowhole is Tennessee's largest known Indiana bat hibernaculum, anecdotal reports of experienced cave scientists participating in research in White Oak Blowhole have observed warmer-than-average temperatures than generally preferred hibernating habitat for these animals.

Note: Historic evidence and discussions about the cave with bat experts suggest that the historic entrance to this cave might have been much larger and has collapsed in geologically recent times creating less than optimal temperatures for these bats by restricting airflow. Observable subsidence around the current entrance supports this assumption and appears to have been accelerated due to storm water reroute from gate construction.

Paleontological, Archeological and Historical Inventory

Limited information has been published on the archeology and cultural resources associated with cave use in Great Smoky Mountains NP. Historical accounts of use of park cave and karst resources include saltpeter and surface mining, speleothem removal, storage, commercial tourism and recreational use. Park archeologists speculate prehistoric use of several park caves. One such cave, Gregorys Cave, has what is suspected to be a prehistoric charcoal drawing of a wild turkey (GRSM *No Date*).

Permitting, Access, Protection and Rescue

Permits

At the time of publication of this plan, all caves (recognized and potential discoveries) in the Great Smoky Mountains National Park require a permit to legally enter. Permits fall under several different departments depending on the type of use requested. Scientific research within caves is permitted through the Resource Management and Science Division. Scientific research is proposed in the application process with detailed descriptions of methods and materials as well as protocols for collection of specimens, etc. The application is reviewed for validity and potential contributions to the scientific body of knowledge

Accepted applicants for scientific permits for study in caves currently receive a protocol for pre- and post-entry decontamination of equipment and clothing. This is to minimize the potential for introduction of non-native entities into the cave as well as meet the requirements based on the United States Fish and Wildlife Service's guidance related to possible transmission of the fungus associated with White Nose Syndrome (USFWS

WNS website 2011).

Non-scientific (e.g., recreation, exploration) permits are obtained through the Resource and Visitor Protection Division as either a special use or recreational caving permit. The author's discussions with local cavers suggest that recent attempts to obtain either type of permit for GRSM cave access have been very difficult. Lack of communication with permit applicants by GRSM management for reasoning behind declining permits has resulted in frustration and lack of compliance of GRSM cave closures. Historically, non-scientific permits (mainly for cave exploration) were obtained from the District Ranger responsible for the areas in which the caves occur. Prior to the writing of this plan, permitting for exploration had been a joint effort managed mainly by the Chief of the Resource and Visitor Protection Division, although anecdotal conversations with members of local NSS groups suggest that recreational permits have not been issued in the past several years. It is unclear if protocols recommended by the Resource Management and Science Division are/would be enforced on those intending to enter a cave for reasons outside of scientific use.

Access

The GRSM staff assists scientists with obtaining keys for cave gates and locations of caves necessary to fulfill their research requests. Non-scientific permit holders can obtain keys from the district ranger office and under normal circumstances; no guidance is given as to the location of cave openings.

Note: At the time of writing of this plan, current cave gate locks use a discontinued standard gate key. This key/lock combination has been replaced due to numerous unaccountable keys and should be discontinued for caves as well.

Protection (gates and signs)

Few known park cave entrances are currently protected from illegal entry by gates; only three of the seventeen known cave entrances have gates (White Oak Blowhole, Rich Mountain Blowhole and Gregorys Cave). Signs warning against illegal entry at several cave entrances are illegible, or have been vandalized or removed (Tory Shields Bluff, Calf Caves I and II, White Oak Blowhole and Saltpeter Cave). Currently, only one cave entrance has an intact, legible sign. An interpretive sign on the gate to White Oak Blowhole misidentifies the cave as a “mine”.

Search and Rescue

Current policy for rescue operations in cave environments in GRSM is managed under the GRSM Incident Command System (ICS). Because of the highly technical nature of cave rescue, rescue operations in GRSM cave environments employ the external expertise of the Knox County Volunteer Emergency Rescue Squad's high angle rope and cave rescue crew. Their specialized training and proficiency in performing cave rescues is far superior to what could be expected from the multidisciplinary nature of GRSM rescue personnel. All in-cave operations are done without GRSM personnel to the degree necessary to effectively respond and provide care to injured persons within the cave. Patient care, once outside of the cave environment, likely falls on those responders most qualified (either GRSM medic or responding emergency medical technician-EMT). Currently no GRSM staff is required to assist any in-cave operations.

GRSM Cave and Karst Management Framework

NPS Staff Responsibilities

Karst terrain is one of the most dynamic landscapes on earth. Understanding of the resources in a karst system can be very challenging due to nature of its underground components. Few resources are protected with federal legislation the way that caves are. GRSM should focus specific management efforts on these resources to develop a program effective at protecting them at all stages of development indefinitely.

Superintendents Office

The Superintendent's office is responsible for decision-making related to permitting additional activities not discussed in the Permitting and Permitting Procedures of the Cave and Karst Management Plan.

Division responsibilities

Resource Management and Science Division

The Resource Management and Science Division plays one of the largest roles in the protection of caves and karst of GRSM. It is the responsibility of this division to continue to move forward with inventory and understanding of resources associated with these environments. GRSM should be proactive in supporting research in karst/cave/mine science to better understand these resources. As GRSM becomes more familiar with the resources associated with these environments, monitoring protocols should be put in place to prevent and document changes. As changes occur, managers need to determine whether anthropogenic forces are at the root of the change or if these processes are natural

(See also RM&S Inventory and Monitoring Protocols).

The Resource Management and Science Division should lead coordination efforts with other federal agencies (e.g., USFWS, USFS), Universities (e.g., Western Kentucky University, University of Tennessee), and other stakeholders (e.g., the National Speleological Society and Tennessee Cave Survey) in order to achieve the GRSM Cave and Karst Management Objectives.

Resource Education and Interpretation Division

It is the responsibility of this division to educate the public on the processes and resources associated with karst environments. As visitor use in these areas increase, it is paramount to the protection of these resources to educate the public about the concerns and management of these areas. The use of signage as well as direct contact during period of heavy use can help deliver GRSMs message on protecting these delicate resources.

Resource and Visitor Protection Division

The main role Resource and Visitor Protection play in the management of cave and karst resources is by focusing protecting on these areas during periods of high use and periodically when time permits. In addition to familiarizing themselves with the location of these resources, periodic patrols of the area are needed to protect these areas from vandalism.

See also Safety and Training: In-Cave Search and Rescue.

Facilities and Maintenance Division

The Facilities and Maintenance Division is responsible for maintaining current and legible signs at cave entrances and in karst areas.

Department responsibilities

Cave Specialist or Cave and Karst Liaison

In order to best achieve the GRSM Cave and Karst Management Objectives and in accordance with RM#77, the Superintendent or Chief of Resource Management and Science should select an employee to coordinate park management efforts and the development and fulfillment of a cave and karst program under Resource Management and Science.

The Cave Specialist (or Cave and Karst Liaison) will be responsible for:

- needs assessment and planning related to cave and karst resources,
- inventory and monitoring coordination of cave and karst resources,
- coordination of cave-related scientific research and cave exploration-access needs,
- review and recommendation of permit applications and all access,
- consultation with staff specialists on cave-and karst-related resource management concerns,
- coordination with Chief Ranger, law enforcement staff and cave rescue organizations (e.g., Knoxville Volunteer Emergency Rescue Squad) to address resource concerns and ensure search and rescue preparedness and resource protection,
- coordinate with Resource Education staff to provide educational and interpretive opportunities, develop interpretational signs and information,
- conduct outreach to local communities, universities, and other interested groups.

Regulations and Permitting

Regulations

General restrictions and guidelines within Caves

Management of caves will follow epigean landscape boundaries, including any future wilderness designation or where cave passage leaves the park.

- No open flames or fires
- No camping within caves
- No use of cave water, either flowing or stationary, for washing of hands, body, gear, equipment etc.
- No activities that disturb or degrade water quality within caves.
- No persons under the age of 16 shall be admitted into any cave or mine.
- No admittance into any vertical cave without updated/safe SRT (single rope technique) equipment. This is the responsibility of the individual and the group.
- No admittance into *any* cave during bat closure period (September 15th - May 15th) without explicit permission from the Resource Management & Science and Visitor & Resource Protection Divisions.

- When applying for scientific or recreational permits, applicants should sign a Cave Access Release Form (Appendix C) to acknowledge and demonstrate their understanding of the risks and requirements involved in cave access in Great Smoky Mountains National Park.

Decontamination Protocols

Decontamination protocols pertain to anyone accessing caves directly, those doing research in karst areas within GRSM, and those who have visited other GRSM karst areas or karst areas outside of the park.

Caves have the potential to have much more stable environments than their neighboring epigean environments. This constant environment has lead to evolutionary processes resulting in ecosystems/species with often very delicate thresholds to invasive species (Culver et al 2003; NYU Website 2008).

Note: At the time of the writing of this plan, two current concerns to GRSM in cave and karst management are White Nose Syndrome (WNS) in cave bats and the Chytrid fungus associated with global amphibian decline. Both fungi have been found in GRSM cave/karst environments.

- *Geomyces destructans sp.* is the White Nose Syndrome (WNS) fungus associated with mass mortality in cave bats.

- *Batrachochytrium dendrobatidis* (Bd or "chytrid") is a fungus described as infecting amphibians and causing the often fatal disease, chytridiomycosis. It has been suggested that Bd is a contributing factor to the global decline of amphibians.

In many cases, simple decontamination procedures can help sufficiently reduce the risks associated with these two diseases as well as other potential risks to cave and karst resources and associated habitats.

For decontamination to be effective, procedures must be followed without compromise. Gear must be clean and free of debris and organic matter.

- The USFWS recommends decontamination procedures to prevent human-assisted spread of WNS. Current decontamination protocols can be found on the USFWS WNS website (2011) and are often updated.

- To prevent the human-assisted spread of Bd (chytrid), a variety of decontamination protocols exist. The USFS suggests methods detailed in Johnson et al. 2003, including submersion in a 7% bleach solution for 10 minutes.

- Use of a 10% bleach solution on all clothing, footwear and gear (where safety will not be compromised) will decontaminate for both WNS and Bd. Gear that has been used in the past in an affected site would not be used in GRSM .

Note: To eliminate any potential for human error, the safest approach to preventing the introduction of foreign species or other harmful agents is to use new or equipment and clothing that has not been in caves outside of GRSM. GRSM has committed equipment for such purposes.

Permitting and Permitting Procedures

All cave access will be permitted through either a Research or Recreational permit. Exceptions may be granted for administrative purposes but should be strictly documented. Park- and cave-specific research and recreational permit applications or special use permits could be developed in conjunction with the Cave Specialist/Cave and Karst Liaison based on the guidelines below.

1) National Park Service Research Permit

A National Park Service Research Permit is required when access to a cave is needed to conduct scientific research. Research is defined as the collection of any information for the sole purpose of adding to the greater body of scientific knowledge. Research permits follow the approved online permitting process for all NPS units found at (http://science.nature.nps.gov/research/). A few examples of activities within a cave requiring use of a research permit are the collection of invertebrates, evaluation of winter bat use, and cave survey/cartography. Park personal should support research permits when there are no adverse effects to the cave or karst resources or other park resources. Additional restrictions and requests must be made through the superintendent's office (i.e. speleothem removal, cave diving, and cave digging).

Species and Sample Collection from within Caves

A valid research permit defining species or sample collection information should/must be present and remain with researcher and collections. GRSM should make all attempts to track specimens for future research needs.

Biological

Cave dwelling organisms often occur in reduced numbers compared to epigean relatives. Consequently, these organisms often live much longer lives and require additional protection from over collection. Collectors should focus on adult males as most are defined to species based on them. Requests to collect juveniles as well as females should be supported if necessary to identify a species more in depth or field differentiation is impossible (Barr 1968; Elliot 2005).

In many cases obligate cave species exist beyond the cave, as we know it and into the mesocavern (small openings adjacent to caves too small for human penetration) and epikarst (small voids of water and air perched above a cave and below the epigean environment). This provides additional habitat for these species often unaccounted for by survey techniques. Many researchers count on these areas as refugia for these species suggesting over collection within a cave is much more difficult than once imagined for most invertebrates (Elliott 2005).

Speleothems

Removal and the study of cave formations have recently led to information supporting paleoclimate change. The removal of GRSM cave formations should be supported with a permit from the superintendents office only when additional sources from outside the park are not available. Restoration and replacement of removed speleothems is a viable option (Hildreth-Werker and Werker, 2006). GRSM's caves lack high numbers of mineralogical resources. Only Gregorys cave is likely to produce useable specimens. With such limited resources, management should consider outside sources or restoration measures prior to permitting and supporting these requests.

Artifacts

The recovery and preservation of cave artifacts are the responsibility of the National Park Service. Permitting for such actions is prohibited.

Survey/Mapping

Several caves within Great Smoky Mountains National Park have had significant cave surveys completed and associated maps have been generated. Known caves that have not been mapped should be permitted through the research permitting process. Access should follow respective closures due to seasonal restrictions and WNS. See also New Cave Discoveries and New Cave Passage Discoveries for additional guidance.

Current survey should be, at minimum, grade 5 quality (Compass and tape survey: Directions and slope by calibrated instruments, distances by fiberglass or metallic tape, or lazar distometer) with intent to create a map for publication through submission to the Tennessee Cave Survey (TCS) in accordance with TCS Map Standards (TCS website 2011).

New Cave Discoveries

Upon discovery of a new cave, the NPS should be notified and the discoverer should apply for a research permit to conduct survey of the new discovery. Once the discoverer has applied for the necessary research permit, a temporary permit should be given in the interim to allow the survey process to begin at the park's discretion.

Once survey begins, surveyors should adhere to good caving ethics and correspond with NPS personnel with regards to resources encountered. Significant and/or delicate resources such as formations or large bat clusters should be cause for temporary suspension of permit until resources can be further evaluated by park staff. The NPS should encourage and support a thoroughly documented survey of the cave and all its resources. Through the research permitting process, information obtained by researchers will be requested by the NPS and failure to do so could result in delayed/declined permitting in the future.

New Cave Passage Discoveries

New discoveries within a cave should be permitted through the research permitting process. If entry into the cave was done through a research permit, survey of new passage is covered by existing permits that grant such activities. If entry into the cave is done through a recreational permit, survey is not allowed without first applying for a research permit requesting access to survey undiscovered/undocumented passage. As is the case with new cave discovery, it is at the park's discretion to administer a temporary permit to allow the survey process to begin after the discoverer has applied for the requisite permit.

Requests for research permits for cave survey should be evaluated to eliminate unnecessary permitting without cause. The NPS supports and gains valuable information from cave survey and would strive to build solid relationships with cavers interested in survey. In many cases, valuable cave survey has been lost or is unable to be retrieved due to poor relationships with past survey cavers.

2) Recreational Caving Permit

Recreational Permits are required when access to a cave is granted for recreational enjoyment of the cave resources. A recreational permit will be obtained from the Resource and Visitor Protection Division. Recreational permits will be reviewed by the Cave and Karst Liaison/Cave Specialist (or chosen representatives of both the Resource Protection [Chief or Supervisor-Cades Cove sub-district] and Resource Management and Science Division [Chief, Specialist, Biologist, or panel]) before authorization is granted.

Not all caves are open to recreational activities. See Potential Recreational Opportunities for more information on caves suitable for recreational use.

3) Additional Permitting Requirements

Diving

Limited opportunities for in-cave diving in GRSM caves exist. Currently, the only known possibility is the sump area in the back of White Oak Blowhole Cave. The sump has had one diver attempt to "push" the cave depth and length in this area but was turned around due to silted water conditions and tight passage. The potential for extensive cave passage beyond this area justifies the support of additional attempts.

Any such efforts would be permitted through a specialized permit from the Superintendent's office.

Cave alteration

Digging, bolting and/or other physical changes (speleothem removal) to a cave or potential cave that may cause an alteration must be permitted SEPERATELY from all other permits (research or recreational) by the Superintendent and Chief of Resource Management and Science. Permits for alteration should only be considered in conjunction with research permits; recreational permits should not require ANY physical alteration.

The Superintendent and Chief of Resource Management and Science should evaluate permits for digging, bolting (including replacement of any failing rigging) or other alterations as to potential contributions. The permittee must justify the necessity for the alteration as to what significant knowledge/resource is presumed to be discovered that will add to the body of knowledge. The park should require that additional resources that are discovered as a result of alteration are surveyed and reported to the park. Because of the stable environment in caves, any physical alteration (including digging and addition/removal of bolts) of a cave could constitute impairment of the resource indefinitely.

Digging and similar alterations must be done at a minimum in order to reduce potential impacts to natural air and water flows. Use of explosives and mechanized devices for enlarging passages is prohibited. Any alterations that impact significant resources (including but not limited to biological, geological, and historical) should be discouraged. Pre- and post alteration photo documentation should be provided with "trip report". After exploration, all materials must be returned to pre-alteration conditions.

Bolting should be restricted to areas with potential for significant resource discoveries (i.e., high leads). All leads must be surveyed. Removal of bolts should be evaluated based on need for further exploration in the area; if lead is a "dead end", bolts must be removed, and lead and lead location must be reported to park as such. Bolts that have been placed in an area that leads to significant discoveries should be evaluated before removal. Bolts leading to recreational or additional scientific opportunities should also be evaluated before removal.

The replacement of bolts should be supported as their use in key locations in caves prevents resource damage by use of natural anchors. In addition, deteriorated rigging should be removed/replaced if safety concerns are evident.

Permittee responsibilities

General

It is the permittee's responsibility to correspond with GRSM to obtain any assistance or keys to enter caves managed by the park.

The permittee is responsible for contacting GRSM before and after visiting any cave on the day of the visit.

It is the permittee's responsibility to have someone above ground capable of contacting the park if the permittee's party is overdue, this will be done *before* there is any attempt to contact or deploy a search party or rescue group.

If a permitted date for entry into a cave or mine cannot be met (e.g., inclement weather, high water) and an additional permit can not be obtained, it is the permittee's responsibility to work with GRSM to establish if a secondary date is available.

Trip Report

All groups entering any GRSM cave are highly encouraged to fill out a detailed trip report. GRSM will provide a resource specific report to be filled out and returned to RM&S Division (Appendix d). In addition to the resource report, all groups are encouraged to write a "trip report" to be filed for each specific cave. These general trip reports should be the highlights of the group's trip. This information can be extremely important to management when determining management concerns as well as be a very useful tool to understanding the conditions within a cave at a given time. Trip reports are used extensively in cave management for documentation of trips into caves.

Resource

All users of caves and mines in GRSM need to play an important role in resource protection and safety. Permitted individuals or groups need to assume responsibility for the monitoring and management of these resources. Every visit into a cave or mine should be followed up with a detailed resource report to the NPS with an in depth evaluation of the resource condition. In particular, the park will require that the observation of any previous wrongdoing, resulting in resource degradation and including illegal entry, should be reported. Appendix d shows a basic resource report that covers a wide variety of management concerns.

Protection and Restoration

Gates

Caves

Gates are a suitable method of cave protection that come at a cost to the aesthetics and, if constructed incorrectly, can interrupt natural processes that bring nutrients into caves. Gates can also have negative affects on air circulation and should only be considered as a last resort.

GRSM gates need to be evaluated for negative effects on the physical parameters of cave entrances. All cave gates on a natural cave entrance should meet the American Cave Conservation Association's accepted cave gate design. This design affords the best methods to control illegal entry while protecting natural processes and without compromising bats' ability to both ingress and egress the cave.

Even the best gate design can significantly alter natural airflow patterns and transport of organics into a cave. Resource managers should be aware of the possibility of altering natural processes and entrances when considering gating as a management tool. Gates that are already in place serve important roles but should be monitored to assure that natural processes are not altered while still fulfilling the initial intent of the gate.

White Oak Blowhole Cave's gate restricts natural surface water flow from carrying organics into the cave. These organics are the nutrient base for many forms of life within the cave. This gate should be monitored to determine if the gate can be altered or if additional measures need to be taken to assist with organic material transport into the entrance of the cave. In general, the gate must be cleaned occasionally to ensure natural flow of organics and air into the cave. In addition, after the construction of the gate, surface water has created a secondary route into the cave. This will eventually lead to erosion and additional entrance locations into the cave. This location needs to be monitored and future modifications considered.

Signs

GRSM caves and karst terrain are concentrated in only a few areas of the park. Most of these are in the Cades Cove management district and easily accessed by well-defined social trails. These trails have developed out of an interest in caves or unique karst features (e.g., waterfalls and high wildflower diversity). In many cases signage needs updated or replaced, and several areas warrant additional signage.

Caves that can easily be discerned are candidates for signage at the entrance. Care should be taken not to deteriorate the aesthetics of the cave entrance area. Caves that are difficult to see or obscured by natural means should not retain signage that might inadvertently disclose the location of the cave. Listed below are caves that need updated or additional signage.

Gregorys Cave – This cave needs to have a sign at the entrance detailing that "…permit is required to enter any park caves…" Regardless of the cave gate, visitors continue to enter the beginning of the cave up to the gate. Fires have recently been lit inside the entrance and fireworks shot into the cave through the gate. It is also an option to add an interpretative panel in the vicinity of either the trailhead to the cave, road leading to the cave, or at the cave entrance explaining the sensitivity/management concerns with GRSM caves and karst. Visitation to this location warrants outreach to the public

Tory Shields Bluff Cave– Current signage is illegible and should be replaced with current wording, "…permit is required to enter any park caves…". An additional option is the removal of any sign as the cave is difficult to locate and identify.

Historic Bull Cave – A steep eroded trail leads down the last portions of Bull Sink to Bull Cave's massive twilight entrance. Signage at the immediate entrance would detract from the aesthetics of this entrance. A sign just prior to the steep portion of the social trail to the bottom of the sink could be used to notify that a "…permit is required to enter any park caves…and travel beyond this point is strongly discouraged…" The remainder of this trail, as it makes its deep decent to the entrance, travels near critical habitat of a rare liverwort. The trail is also a source of sediment into the cave/karst system. Visitation to this cave entrance is high.

Calf Caves (I and II) – The large sink that encompasses the entrances to both caves needs to be resigned as the previous sign has been recently stolen. This could be a simple "…permit is required to enter any park caves…" or could be used to educate the public of the sensitivity of GRSM caves and karst. This set of entrances is on the way to the Historic Bull Cave Entrance and could be a good location to capture the high number of visitors that walk to both locations.

White Oak Blowhole Cave – the sign at this cave should be replaced. The current sign misidentifies the cave as a mine. Due to the already aesthetically unpleasant gate on this cave, the entrance to White Oak Blowhole may be a suitable location for an interpretive panel describing the sensitivity and management concerns related to caves and karst, especially White Oak Sink. The importance of this cave could also be highlighted in conjunction with information on White-nose Syndrome in Tennessee and North Carolina specific to GRSM. Visitation here is extremely high, especially during the spring/summer.

White Oak Salt Peter Cave – The signage at this cave is illegible. It is also uprooted and often on the ground. Replacement is necessary and relocating it to the edge of the sinkhole might alleviate some traffic that is currently drawn to the cave entrance by the ageing signage. This sign could be the general "…permit is required to enter any park caves…". This cave receives the highest amount of illegal cave entry of any cave in the park.

Scott Gap Cave – the current signage at this cave is still suitable and needs only to be changed if the current wording is found to be incorrect. In addition, a fallen tree is hung directly above this sign, which could become compromised if it should continue to fall or obscure the sign.

Rainbow Cave – The waterfall at this cave's entrance is one of the highlights in White Oak Sink and many people may not be aware of the presence of a cave. The high visitation to this site makes it an ideal location for a miniature interpretative panel or simply a sign stating "…permit is required to enter any park caves…" and also allude to the risks associated with entering GRSM caves.

Karst areas that receive high visitation, such as Bull Sink and White Oak Sink, should have interpretative signage adjacent to trails leading into them to provide visitors with information surrounding safety, access parameters, and management concerns. These should be used in addition to specific cave signage to alert visitors of the delicacy and management of these resources.

Ace Gap Trailhead at Rich Gap – This trailhead is only a few minutes from all the caves on Rich Mountain-upwards of four miles of known underground passages. A general interpretative panel at this location should advise visitors to the sensitivity and dangers of karst areas, GRSM management concerns with caves, as well as visitor's responsibilities. Current national and park concerns with White-Nose Syndrome should be addressed in this area.

School House Gap Trailhead at Laurel Creek Road – This location is likely the best choice for intercepting hikers on their way to White Oak Sink. Signage or even a small kiosk could be used to explain concerns with karst resources, cave related information, or even wildflower information. In addition, depending on future plans with the trail system within White Oak Sink, it could be used to describe the man-ways and social trails as well as concerns with their use and concerns with off trail travel. An introduction to White-Nose Syndrome should be addressed here as well as its national and park concerns.

White Oak Sink's unmaintained trails at School House Gap Trail (Dosey Gap) and Scott Mountain Trail (School House Gap). These are the main social trail access points into the sink. Both lack any signage and depending on how management chooses to deal with the trail system in the sink, need signage accordingly. At a minimum, trail maintenance should be evaluated and provided by the NPS. Additional signage describing that these trails (man-ways) are unmaintained is needed.

Gregorys Cave Trailhead – This trailhead receives considerable traffic. There are often several cars parked there throughout the year, specifically during periods of high visitation to Cades Cove. Most individuals encountered on the trail headed towards the cave are aware of a cave at the end of the trail but some are not. This location sees high visitor use due possibly to the presence of an old road and park gate. Signage at the gate could provide information about park caves, management concerns, as well as requirements for entry.

Restoration (cave resources and natural air/water flow)

Currently no information exists to suggest the need for restoration of natural airflow in any of GRSM caves. Alteration (cave gate) of the natural transport of organic material by water into White Oak Blowhole warrants further investigation.

The illegal activities associated with digging open Rich Mountain Blowhole Cave have been corrected from an airflow perspective by installation of an air restrictive gate by the Tennessee Cave Survey. Not only does the current condition closely mimic the suspected pre-digging micro-climate of the cave, it allows for controlled entry into one of the deepest caves in the Eastern United States.

Several GRSM caves have been vandalized but not compared to many caves outside of the park. When paint or other material are used to write names on cave walls, prior knowledge of the condition of the cave must be known so as not to remove historical names which may be obstructed by the new graffiti. The replacement of broken speleothems (including those used in science) should be done with the most current techniques to preserve the integrity of both active and non-active mineralogical resources. There are specialists who can be contracted to assist and conduct these types of repairs if needed (Hildreth-Werker and Werker, 2006).

Safety and Training

In-Cave Search and Rescue (SAR)

NPS-77 suggests outlining cave-related search and rescue activities and tactics in the park’s search and rescue plan, and addressing protection of cave resources to the extent possible. Furthermore, it suggests addressing the park's interaction with outside cave rescue groups.

In recent years, Great Smoky Mountains National Park has developed an informal working relationship with the Knoxville Volunteer Emergency Rescue Squad (KVERS) in regards to conducting in-cave rescue and patient management in caves in the park.

No formal agreement or MOU currently exists between the GRSM and KVERS. In cave rescue situations, the park should provide guidance as to adequate procedures to alleviate or mitigate resource damage within caves (e.g., setting of bolts). GRSM should provide in-cave support or, at a minimum, upfront direction on resource protection decisions during rescues.

It is the park's responsibility to provide organizations such as KVERS with this information in advance of rescue efforts. Cave rescues are dangerous for all involved and it is the parks responsibility to make sure that resource damage is kept to a minimum without compromising the safety of all involved.

Inventory and Monitoring Needs and Priorities

Biological

Cavernicoles (cave dwelling organisms) in GRSM have received extensive attention and there exist several important species requiring specific management. In some cases, there has been no effort to understand the effects humans have on these species. In order for GRSM to manage the use of cave and karst resources by humans, Inventory and

Monitoring protocols need to be developed and implemented. Currently, the only species that is regularly monitored is *Myotis sodalis*, the Indiana bat. In conjunction with the United States Fish and Wildlife Service, Indiana bats are counted in one of the five known hibernacula (caves) in GRSM every other year. Due to the effects of White-Nose Syndrome in cave bats, the USFWS has received pressure to consider federally listing five other cave bat species that use GRSM caves as summer and winter roost sites. With recent counts of these species being done by the author, GRSM needs to continue these surveys to assist the USFWS and monitor potential declines. *Stygobromous fucundus*, the endemic amphipod from Gregorys Cave, was monitored for several years after discovery but monitoring efforts have since ceased (Johnson 1990). Four of the eleven known obligate cave species have not been identified to species and are possibly endemic to the region or the park. These species need to be addressed and further understood before specific management protocols can be implemented. Notably, the microbial community of GRSM caves has not received any attention and has potential to add to the known diversity of the park. As GRSM becomes more familiar with the biology of caves and karst topography, specialists will need to be contacted to fill in the missing information of previously undescribed species, rare biology, and their management application.

In addition to species-level biological inventory and monitoring, resource managers should consider broader inventory of specific habitat (e.g., water resources, guano piles), biological communities (e.g., aquatic, microbial), and human made habitat (e.g., rotting wood left in Greogorys Cave). For example, rather than monitoring individual species of isopods, amphipods and flatworms that require cave pool habitat, resource managers should focus on monitoring and protecting the quality of water in cave pools.

Physical parameters (Microclimate)

Cave microclimate is an important characteristic of caves as habitat for many species as well as play crucial roles in how caves develop. The relationships between airflow, temperature, humidity and evaporation are important to understanding what makes certain areas in a cave optimal habitat for species such as hibernating bats or crickets or could adversely affect the development of cave formations. Any actions changing one of these parameters could cause additional changes resulting in loss of historical habitat for specialized cave and karst species and physical cave resource development. The unnatural opening of a cave passage (either above or below ground) or an improper cave gating activity are all known causes of microclimate degradation in cave systems and should be avoided except in extreme cases where documentation can assist in the restoration of the area to pre-alteration conditions.

Radon monitoring should be conducted in accordance with Directors Orders/Reference Manual 50B Occupational Safety and Health Program (RM-50B) and RM-77, Cave and Karst Management, Health and Safety.

In addition to Radon gas, monitoring other ambient gasses within caves can lead to better understanding of the total physical makeup of cave conditions and processes both below and above ground.

GIS layers

The development of a centralized cave and karst set of GIS layers is an important step in making cave and karst resource information known and available to researchers and managers. As information is collected, either internally or by researchers, it can be added to the GIS helping to clarify cave and karst vulnerability. In addition to vulnerable resources, a GIS can help define inventory and monitoring needs such as baseline cave surveys or temperature trends. The development of secure data is paramount to resource protection. *Cave locations on federal lands bound by the FCRPA are not public domain, GRSM must consider information on cave locations accordingly.*

Cultural

Several caves in GRSM have significant cultural resources. At least two caves were mined for saltpeter in historic times, and in both cases remnants of the operation exist. Records and archeological investigations of Gregorys Cave reveal pre-historic and historic use of the cave by Native Americans and early park settlers.

Caves in GRSM should be inventoried to document remnants of pre-historic and historic periods of use and determine significant resources needing protection or restoration.

Hydrological

Most caves in Great Smoky Mountains National Park are currently active, meaning they are still in the process of changing/developing due to the dissolution of bedrock mainly by the addition of carbon dioxide (carbonic acid) brought in contact with the rock by water. As managers, knowing the source as well as the destination of major paths of water through the karst system is of major concern. As with protecting the biology that needs this moisture, the formation of the cave itself cannot be protected without protecting the water that drives most of its processes. GRSM knows very little about the karst hydrology conduits without speculation.

Karst watersheds are unique and frequently unrepresented by surface topography. Dye tracing the karst pathways is the best way of understanding the karst watershed and where to focus management actions at protecting these waters (Beck et al 2001; Palmer 2007). Knowing the surface origin of subsurface water allows for mitigation to prevent contaminants or altered flow regimes from impacting subsurface habitat/communities. The concepts of understanding the whole karst system in GRSM is critical to detecting the affects that neighboring land owners are having on GRSM cave and karst systems.

The physical and chemical parameters (abiotic) of karst water should be monitored to understand changes, especially unnatural ones. Simple monitoring of water chemistry, including temperature, can allow the manager to understand the differences between natural fluctuations and human induced changes as well as their impact on the biological and physical resources within the cave.

Water levels and rainfall are directly related to the karst aquifer. Understanding the seasonal variation and climatic changes are necessary to understanding long term variation within the system. Several GRSM caves have pools (sumps) as low points. These pools signify a point in the aquifer that can be easily measured. In many cases, conversation with long time GRSM cavers suggests a decline in karst aquifer levels at these sumps within GRSM.

As stewards of the land, GRSM needs to understand their role in providing hydrological recharge to neighboring karst aquifers in Dry Valley, TN. Activities both inside and out of the park could negatively affect this resource via GRSM subterranean karst pathways. Karst hydrology can transport contaminants quickly through subsurface conduits and must be managed accordingly.

Human Impact

All known caves in Great Smoky Mountains National Park have received recent human visitation resulting in irreversible impacts to the resource. Normal wear as a result of visitation, such as trampled substrate, and intentional damage such as broken formations or the addition of hardware (i.e., bolts) should be documented and described to establish a baseline for measuring resource degradation due to human visitation. As suggested by RM#77, a system of fixed photo-points can be used to measure resource degradation in caves that may have significant legal or illegal entry. In addition, an attempt to quantify illegal entry and visitation to caves in the park is necessary.

See individual cave descriptions above for narrative of known human impacts.

Potential Recreational Opportunities

Access to GRSM caves have long been pursued by local and distant cave organizations and cavers. Several caves in GRSM possess some of the deepest and most challenging vertical cave passage in the Eastern United States and rival caves on public land across the country in depth and challenge. Supporting the mission of the NPS, the ability to allow recreation in GRSM caves is plausible with a strong proactive cave and karst program. GRSM has suffered poor relations with cave explorers who have defined the resource that make GRSM caves and karst so dynamic. Allowing for limited recreation and flexible access, GRSM has the potential to gain significant knowledge and protection of their resources while fostering positive relationships. Such actions are supported by the FCRPA.

Recreation in GRSM caves should take place exclusively outside of seasonal bat closures and current White-Nose Syndrome closures. Important to any recreational caving program is the parks devotion to monitoring their resources to prevent long term and irreversible negative impact. The investment by nearby grottos (or caving clubs) as stewards of the resource is often a successful collaborative effort across the country and globally. In the US, many grottos or other NSS affiliates have been utilized as a method of cost effective management as recreational visits can be used to collect information on current research projects and to monitor cave resources and vandalism (Brown et al 1999). These trips are beneficial to the land managing agency and allow access by competent individuals who otherwise would not be given the opportunity (Jones et al. 2003).

The Bull Cave System and Rich Mountain Blowhole cave are two of the primary caves of interest to technical cavers. With over 20,000 feet of explored and documented passage between the two, these caves pose considerable challenges. With depths of 924 and 840 feet respectively, both caves possess numerous vertical challenges, in both dry and wet passages. These are caves requiring the best and safest skills in single rope techniques.

The Bull Cave System's Historic Entrance has been known for many years with early exploration taking place in the 60's and countless, undocumented, visits until the late 90s.

The Bull Cave System, on a larger note, can be a complex through trip where two groups would be needed. Each group would rig ropes on one side of the cave's two known routes into the mountain, passing each other in the primary stream passage at the bottom of the cave, and then climbing back out on the other group's ropes. Few caves offer this type of recreational interest.

The cave itself is low impact prone along most of the stream course on the Historic side due to the seasonal flash flooding of the bedrock passage. However, these types of caves have the ability to move sediments into and through the system very easily. This should be a concern and require trip numbers to be controlled. This cave with applied monitoring efforts would be one of the best choices for experienced recreational cavers. Conservatively speaking, a few trips into both sides of this cave every year would be the beginning of strong and positive relations with local cavers and grottos of the NSS as well as local rescue squads. Utilizing Rich Mountain Blowhole as a control by restricting access or implying the same control methods could allow for comparative measures and conclude the need for additional protection.

Other caves in the park with caver interest and minimal expected damage from access would be both Scott Gap Cave and Rainbow Cave. Scott Gap is a simple cave with an easy vertical drop lending itself to basic recreation. More time is spent accessing the cave location than the cave itself. It is also away from major visitor areas. Rainbow Cave is another good choice that offers a few challenging short rope sections in water. Both caves, though relatively short, offer potential recreation with minimal resource damage if monitoring protocols are put in place.

Other, much smaller, caves in the park really don't offer much in the way of recreation by those willing to put forth the effort to obtain a permit. White Oak Blowhole and Gregory cave will always be coveted for their biological importance by GRSM and thus should be protected accordingly. With both having gates, it is simple management to restrict access for science related visits only utilizing cavers as needed support when possible.

Caves such as White Oak Saltpeter and the Calf Caves I and II both receive extensive illegal entry. Permitting for access to these caves will likely not slow resource damage to the cave but could be a method of monitoring if there became interest in recreational visits. Due to their size, recreation does not seem to be a worthy option.

As with all caves in GRSM, the ability to document and mitigate resource damage is the pinnacle of successful resource management of *any* and *all* access, including scientific, illegal and recreational. Use of nearby cavers and grottos as stewards would ensure competence and compliance within the allowance of access.

Developing Cooperative Relationships

The Tennessee Cave Survey and both the East Tennessee Grotto and the Smoky Mountain Grotto of the National Speleological Society (NSS) have been historically very active with cave exploration and cave recreation in the Smokies. The park would continue to develop and in some cases, redevelop these relationships and involve members of these organizations in planning and decision-making about cave and karst resources in the park. The development of specific MOUs with these groups would ensure further collaboration. As the park moves forward and seeks stewards of these resources, the NSS and their affiliated groups should be utilized to foster additional collaboration and technical support. The Cave Research Foundation (CRF) has a strong MOU with the NPS and has also expressed interest in assisting in aspects of cave and karst science in GRSM. GRSM must also continue to foster relationships with universities specific to research in caves and karst. Western Kentucky University, a major contributor to current cave and karst work in GRSM, has worked alongside several NPS units and has played a similar role in the development and support of management through solid cave and karst science. University of Tennessee has expressed interest in working with cave and karst biology, including bats and White Nose Syndrome management, within GRSM. There has been past work with Tennessee Tech University on bats in GRSM as well as other components of cave and karst biology. These relationships are important to understanding what management needs exist and what approach GRSM must take to protect the complex karst environment. GRSM caves and karst bode to benefit from the answers generated from applied science.

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Appendices

Appendix a.

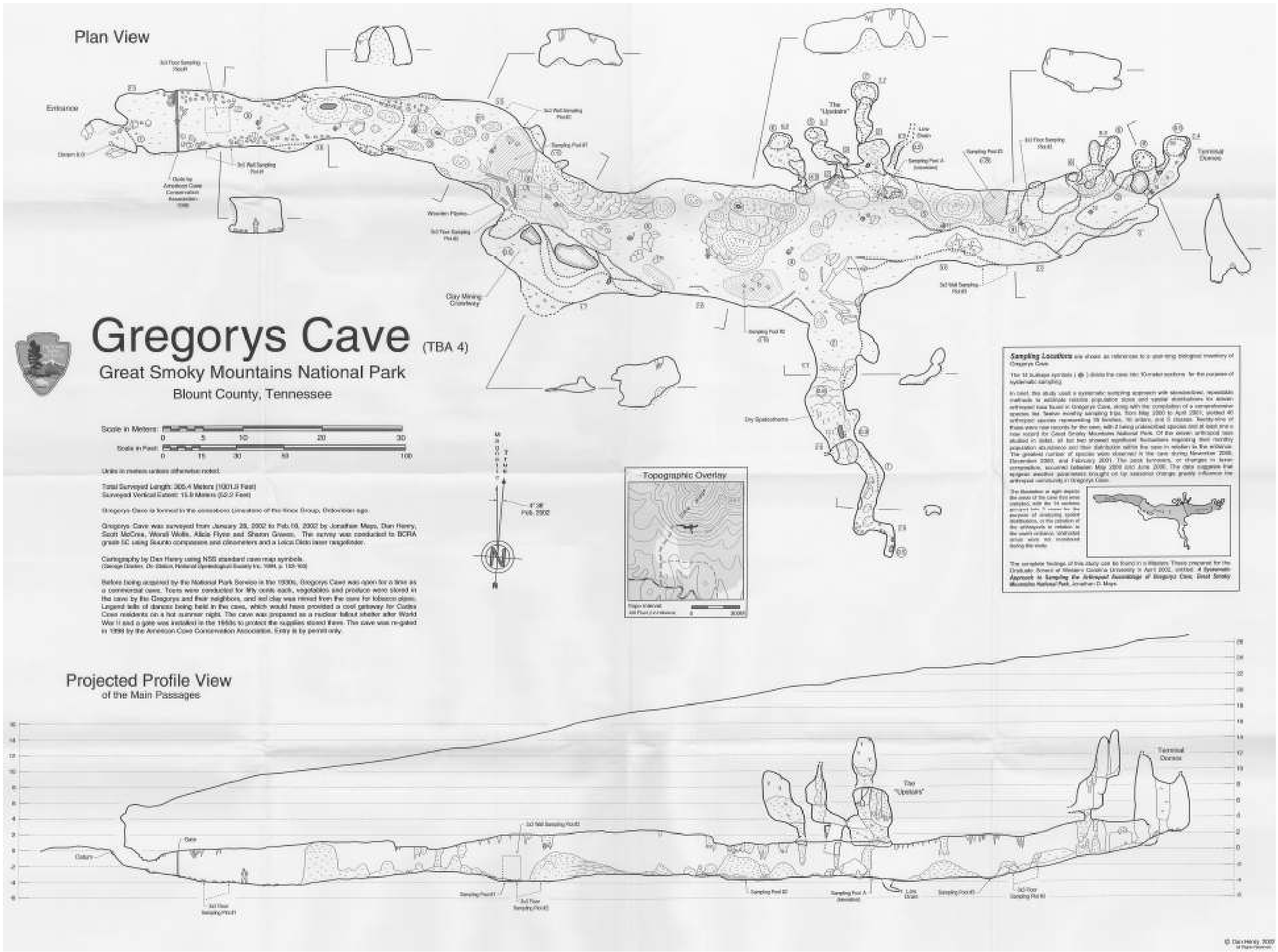
Great Smoky Mountains National Park Cave Maps

Several maps of caves from the Great Smoky Mountains National Park follow. Their content and reproduction are protected from use by © 1998-2011 Tennessee Cave Survey, Inc. Tennessee Cave Survey data and information are proprietary, thus duplication, distribution & use of such is by written permission only.

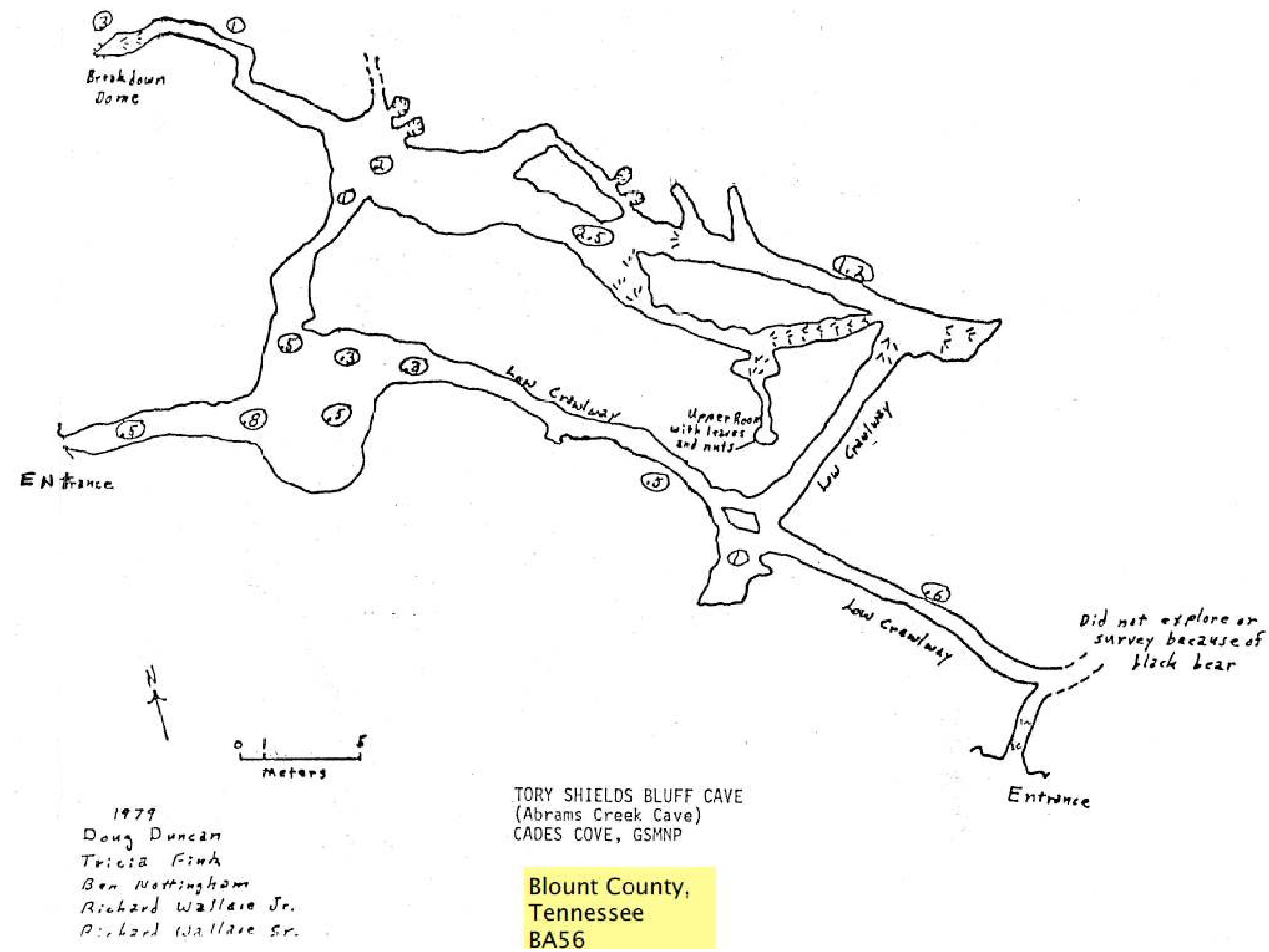
Failure to request permission to use contents as stated herein is considered a violation of the U.S. Copyright Law applicable to the Tennessee Cave Survey and the original cartographer.

Included maps covered by copyright are:

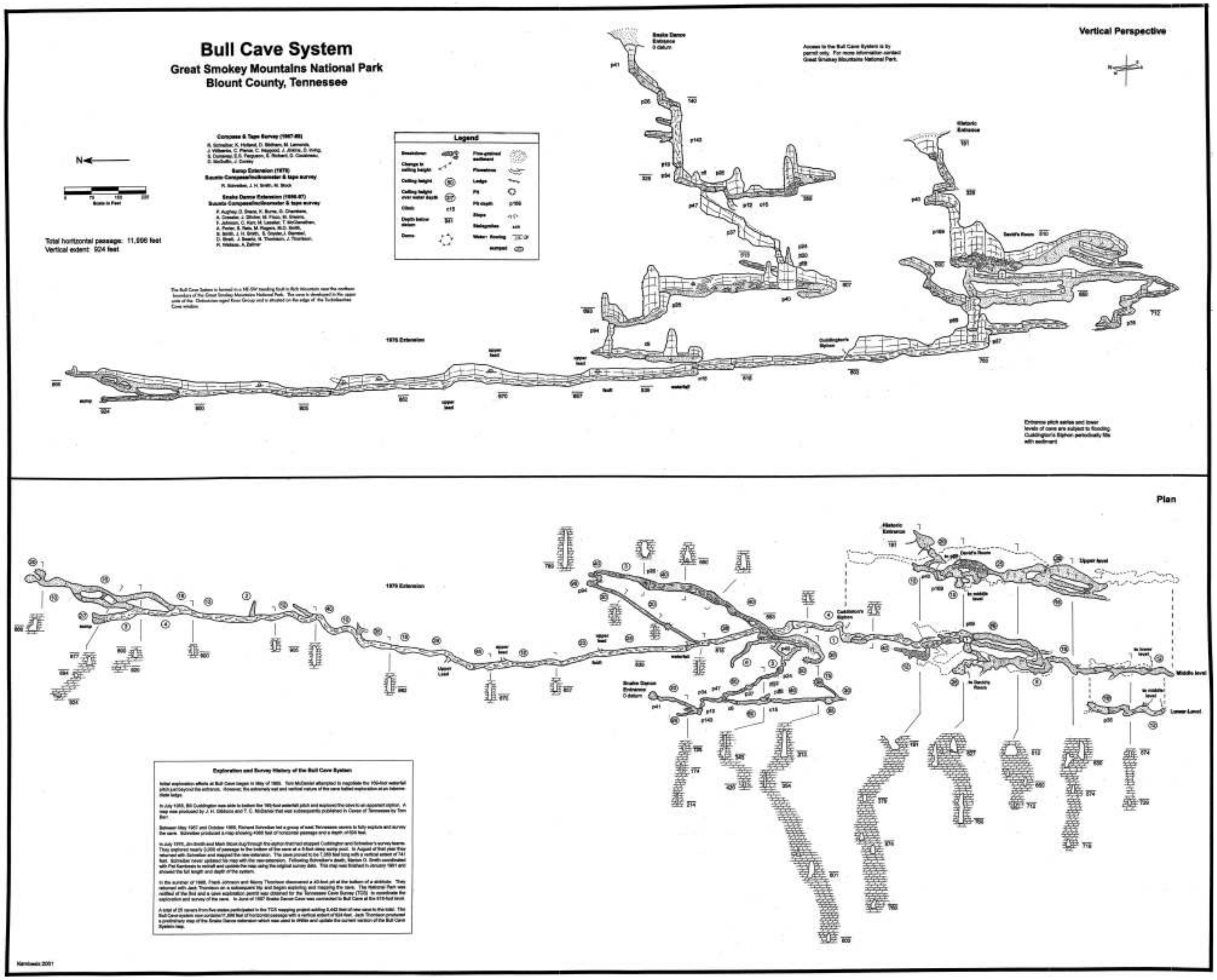
- Gregorys Cave
- Tory Shields Bluff Cave
- The Bull Cave System
- Rich Mountain Blowhole Cave including both the South and North print
- Calf Cave I
- White Oak Blowhole Cave including profile and plan
- Rainbow Cave
- Scott Gap Cave



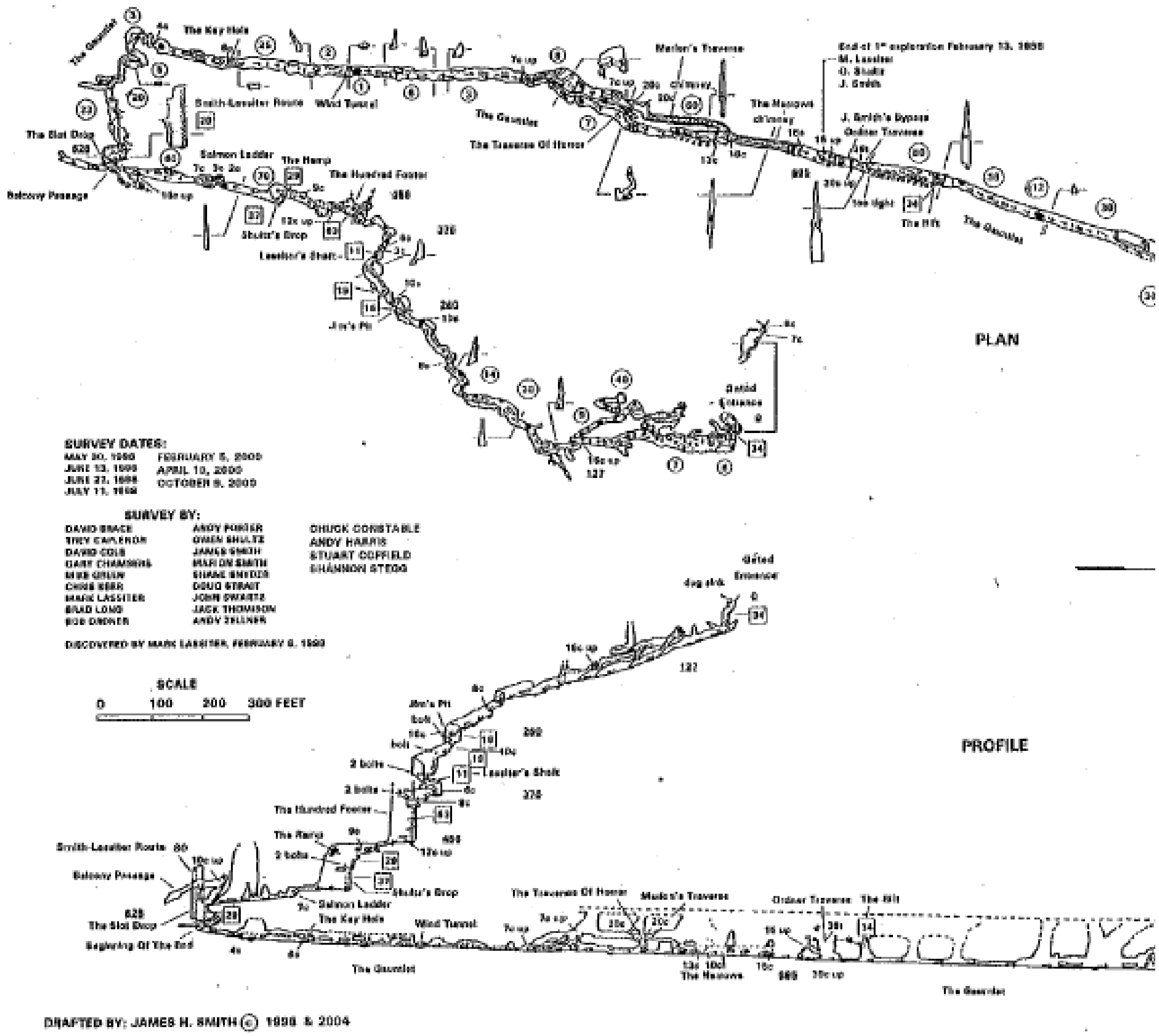
Gregorys Cave Map, Great Smoky Mountains National Park



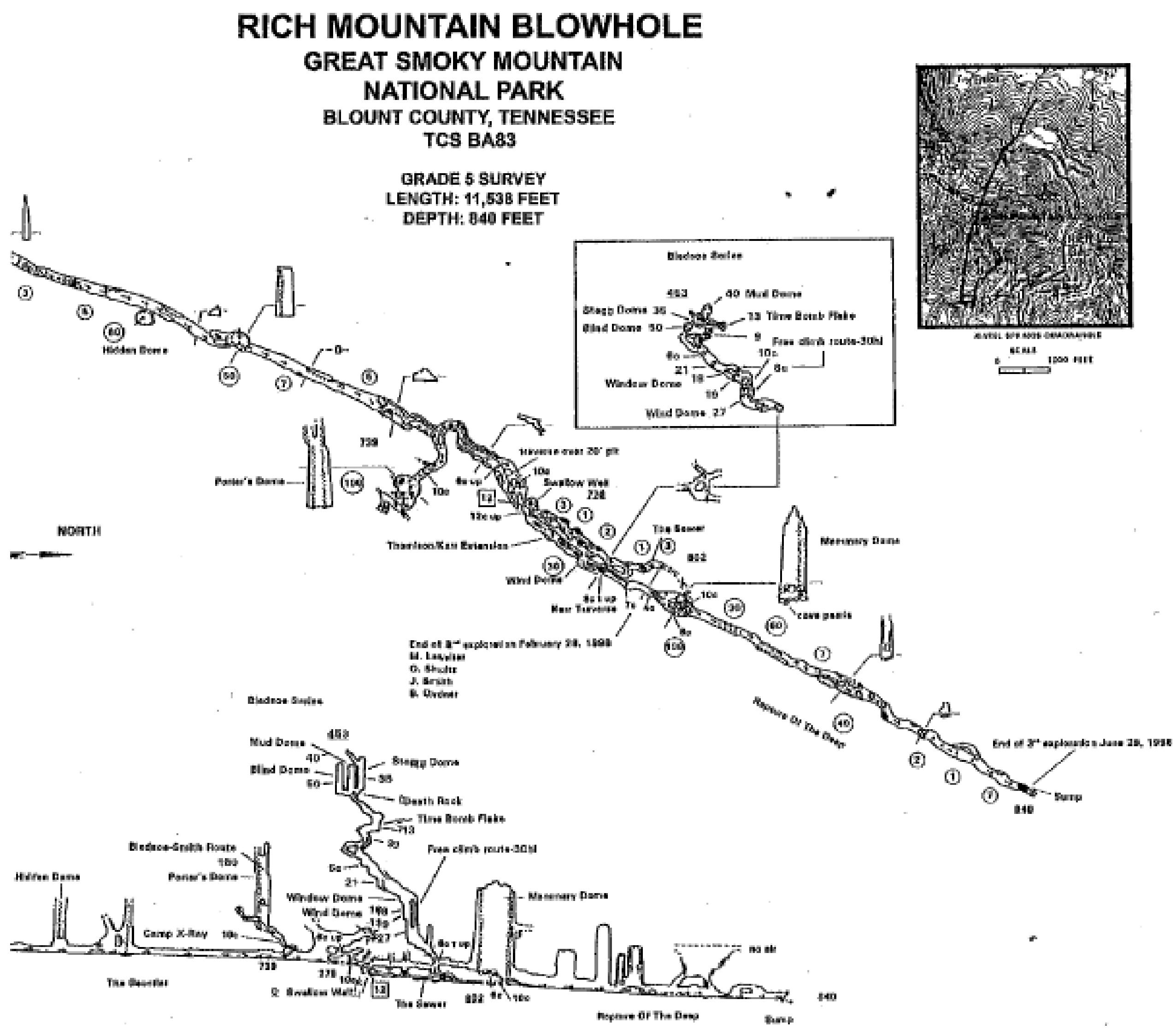
Tory Shields Bluff Cave Map, Great Smoky Mountains National Park



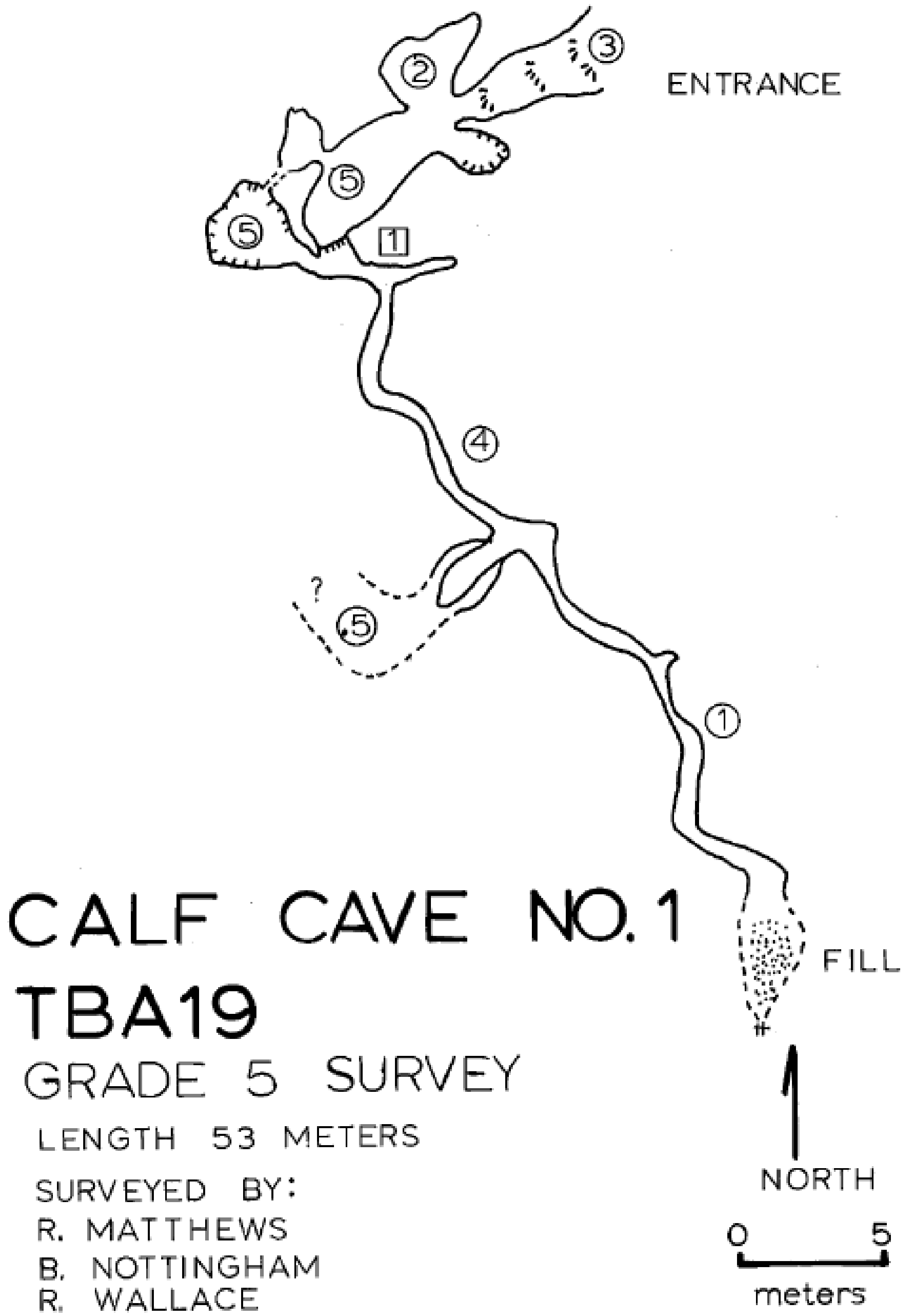
The Bull Cave System Map, Great Smoky Mountains National Park



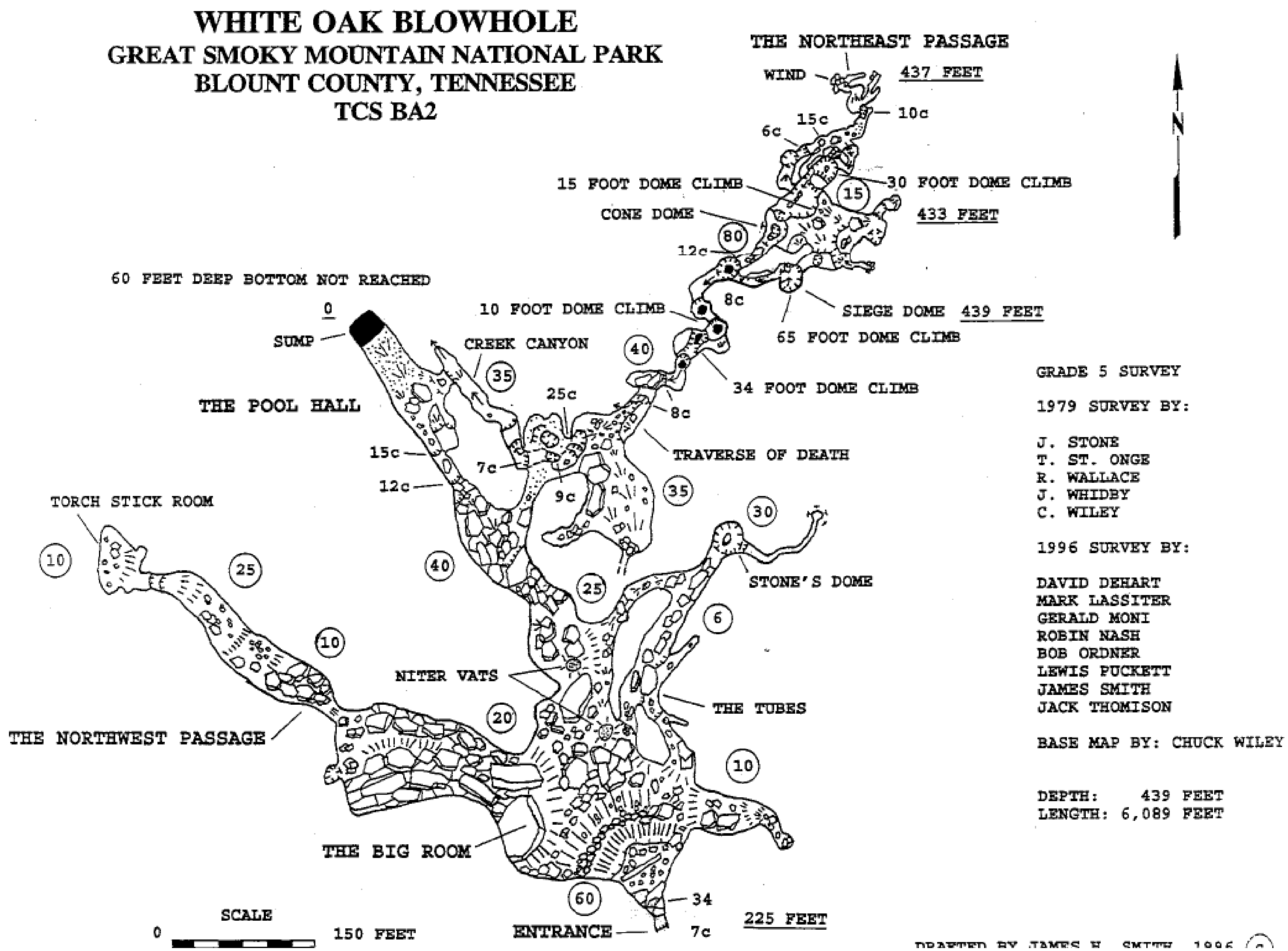
Rich Mountain Blowhole Cave, South Portion of Map, Great Smoky Mountains National Park



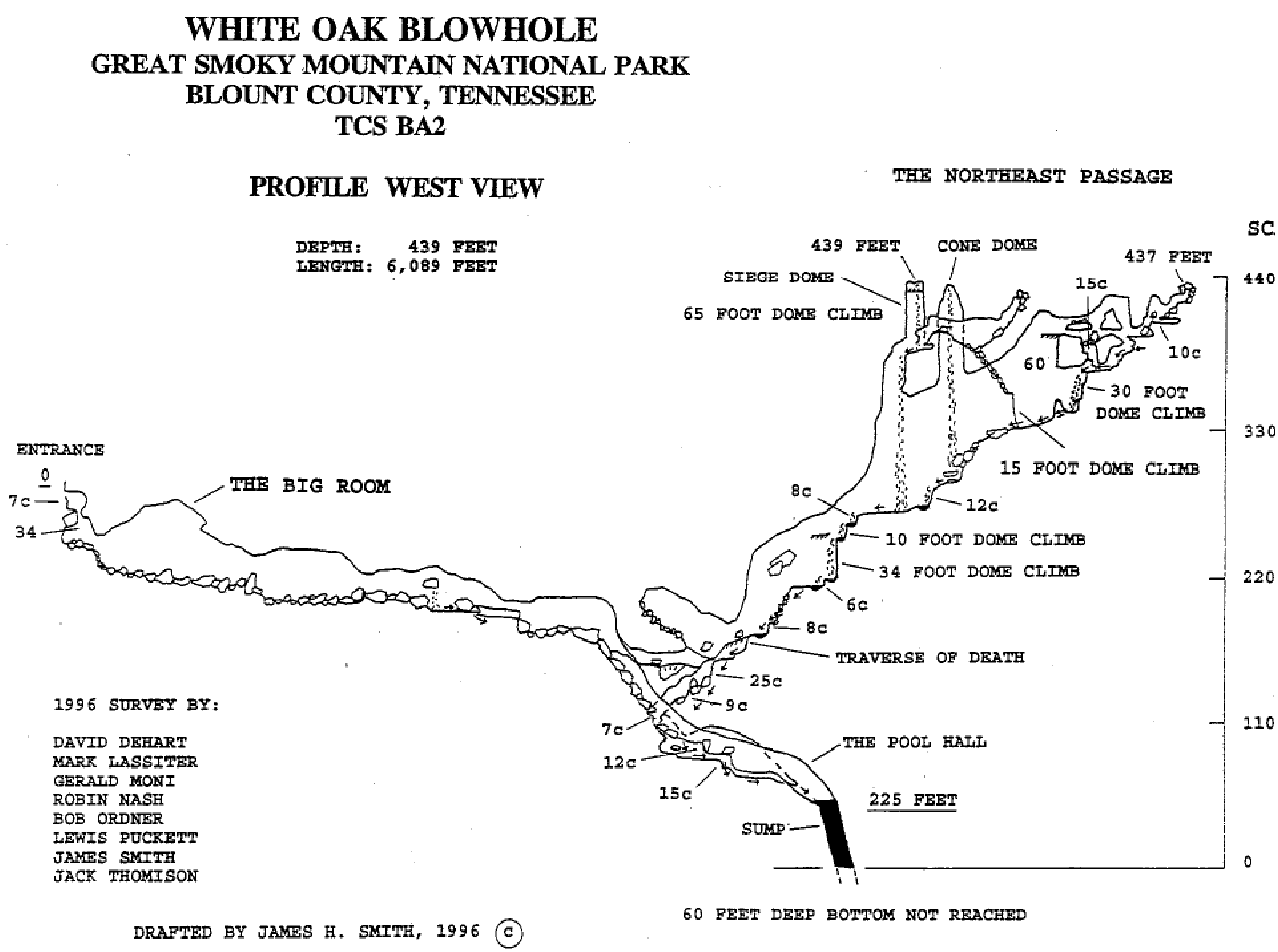
Rich Mountain Blowhole Cave, North Portion of Map, Great Smoky Mountains National Park



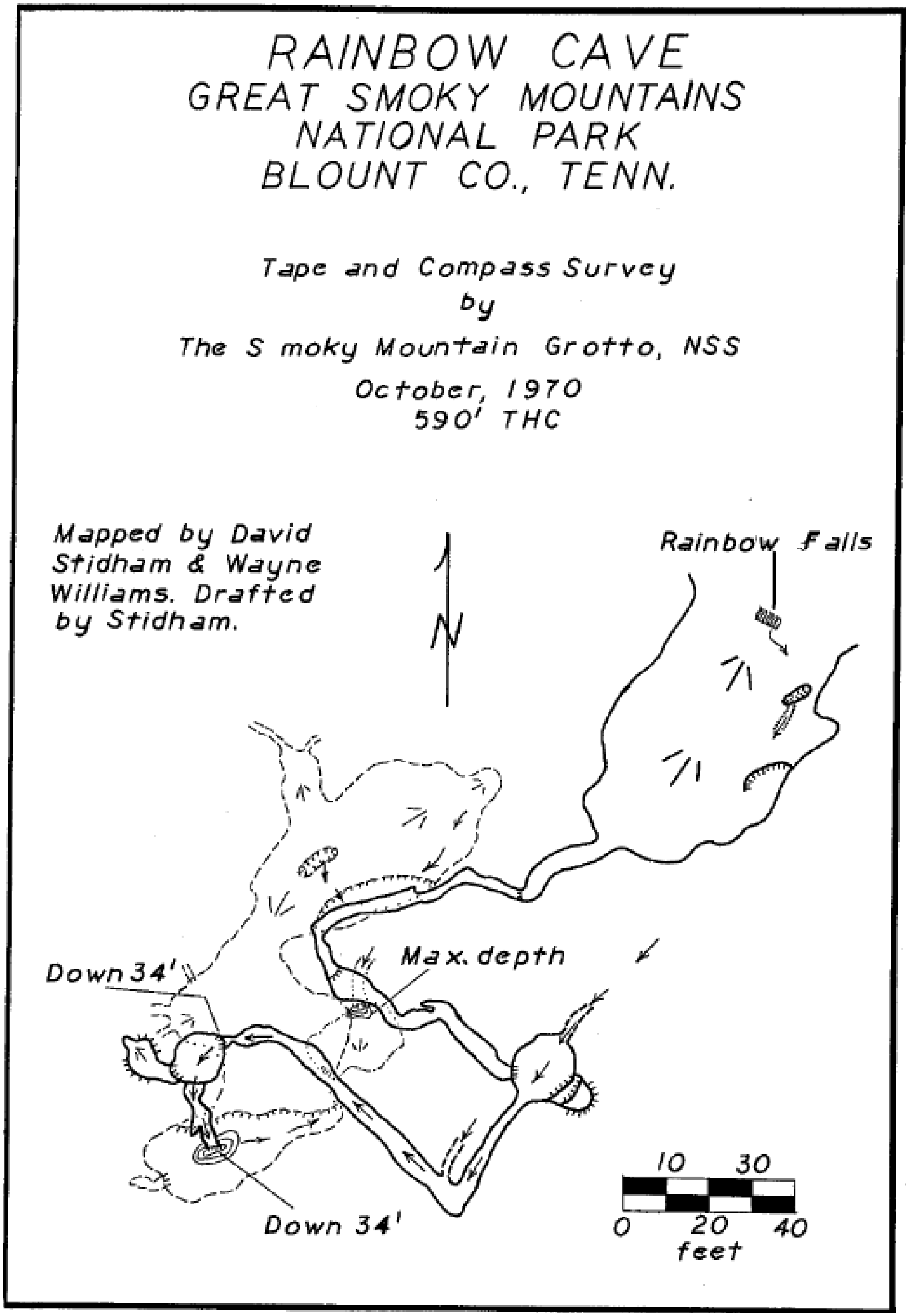
Calf Cave No.1 Map, Great Smoky Mountains National Park



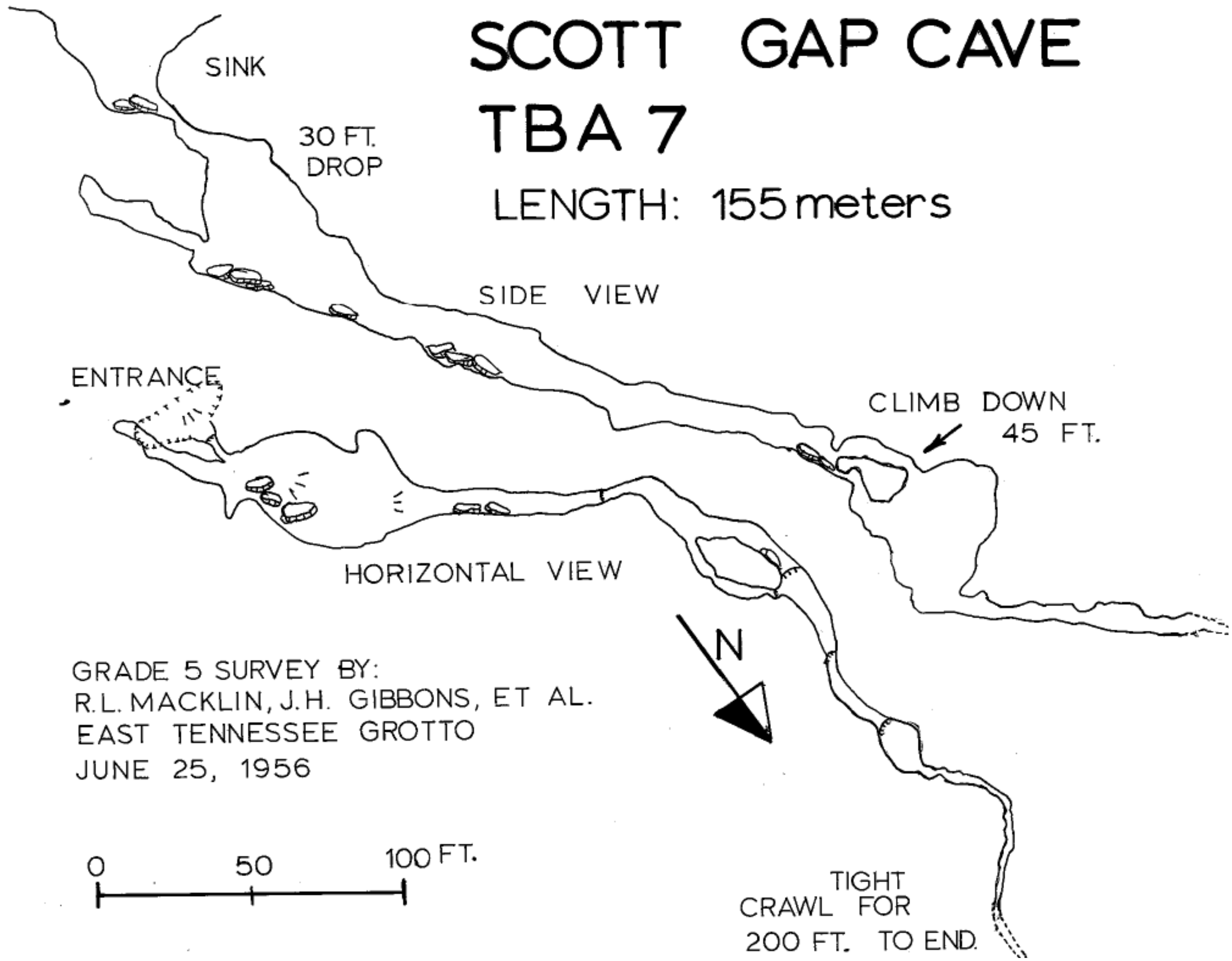
White Oak Blowhole Cave Map-Landscape, Great Smoky Mountains National Park



White Oak Blowhole Cave—Profile Map, Great Smoky Mountains National Park



Rainbow Cave Map, Great Smoky Mountains National Park



Scott Gap Cave Map, Great Smoky Mountains National Park

Appendix b.

Photos Associated with Caves and Karst Resources

Gregorys Cave, Great Smoky Mountains National Park.


White Oak Blowhole Cave, Bat-friendly gate at main entrance.


Rainbow Cave entrance, White Oak Sink karst area.
Great Smoky Fault shown with white arrows.


Sign and entrance to Whiteoak Saltpeter Cave, White Oak Sink karst area.


Sign at edge of sink, Scott Gap Cave, White Oak Sink karst area.

Appendix c.

Great Smoky Mountains National Park Cave Access Responsibilities and Regulations

This form is to be signed by each person entering any cave located within Great Smoky Mountains National Park.

Risks

Caving is a strenuous activity involving climbing, stooping and crawling. Some caves in Great Smoky Mountains National Park require technical expertise in use of ropes and ascending/descending equipment. Any physical condition that limits such activities may affect your ability to safely participate in cave travel. Consider your physical or medical conditions when deciding about your ability to safely take part in caving trips in Great Smoky Mountains National Park. Help takes longer to reach you in the cave than it would on the surface.

Caving is associated with hazards such as low ceilings, slippery slopes, tight squeezes, exposed climbs and deep pits along with potential hazards such as falling rock and hypothermia. It is easy to become lost if you get separated from your group.

Please consider these factors in deciding whether you want to join the caving trip.

Responsibilities and Regulations

1. Great Smoky Mountains National Park's caves and features, including biological, historic and cultural features, are protected. No cave feature will be disturbed n any manner.
    a. Cave formations, minerals and cultural items will not be removed from the cave.
    b. Cave life will not be disturbed or removed without proper permit.
    c. Cave walls, formations and cultural items will not be marked, touched, broken, damaged or altered. Any alteration of the cave must be addressed in a permit before entering the cave.
    d. Each person must be aware of their surroundings to prevent damage to the cave.

2. All current decontamination procedures and requirements supported by the

USFWS must be adhered to. This includes the use of equipment and clothing used in caves outside of the park or equipment and clothing that could be used outside of the park. Check the USFWS' WNS website for current procedures prior to the day caves are permitted for entry.

3. All items brought into the cave from the surface will be returned to the surface. This includes bodily wastes.

4. Every member of the group will:
   a. Wear a helmet at all times while in the cave
   b. Carry at least 3 independent, reliable sources of light.
   c. Stay with the group at all times.
   d. Make sure at least one first aid kit is carried with the group.

I have read and understand the risks and responsibilities associated with cave access. I agree to abide by all park regulations for cave access.

Signature ____ Date _______________

Additional members of trip:

____

____

____

____

____

Please print legibly or type

Name ____

Address ____

City ___________________________________ State _____ Phone __________________

Emergency contact ____

Emergency contact phone ____

Appendix d.

Great Smoky Mountains National Park
Cave Inventory Form

Great Smoky Mountains National Park
Cave Inventory Form

Cave Name:___________________________________
Portion of Cave Visited and Inventoried:__________
____
Recorder:_____________________________________
Inventory date/time:___________________________
Surface conditions:____________________________
Additional personnel (note those who have been in this cave or have knowledge of resources they wish to be credited for):____________________________
____
____
____
____

Instructions:
encourage all members of the party to read and partake

During your visit to the cave, please take note of the resources you encounter. If you have been to this cave before, please note any changes you notice in the condition, numbers of resources, or its general appearance. If you are new to the cave or have experience with cave resources such as geological processes, bio-inventories, resource photography, etc, please fill in any or all of the following observation categories to better help management protect and understand these environments. If you photograph a feature/resource of importance, note that with a "**P**" and some general information about the picture so that future investigations/comparisons can be achieved. Please list contact information for retrieval of any photographs you are willing to share with the NPS and you feel to be of importance to management.
We ask that you answer what you can as honestly as you can with the understanding that you will not provide accounts of all resources.

Computer entry date_____________________________
Data entry by___________________________________

General Observations (Physical)
(if a cave map is present, feel free to reference it directly for exact locations)

Water (make note of where the cave is dry and where moisture is present)
Surface water entering the cave ***YES / NO*** (circle one)
Moisture____
Dripping____
Flowing____
Pool (note size ~ LWD) ____________________________
Flood water line___________________________________
Paleo water line___________________________________

Airflow____
(indicate direction and velocity, if possible, at notable locations)

Floor
Sediment/soil______________________________________
Breakdown____
Bedrock____
Secondary deposits_________________________________
Pit____
Floor slots____
Potholes____
Incised meanders___________________________________

Ceiling
Dome____
Ceiling Channel____________________________________
Bell hole____
Pockets____

Natural bridge_____________________________________
Pit____
Floor slots____

Potholes____
Incised meanders__________________________________

Conservation
Flowstone shoes required____________________________
Gloves off area____________________________________
Restoration projects (possibilities)______________________
Other____

Obstacles
Crawl (anything difficult for rescue)_____________________
Unroped climb or chimney ___________________________
Pit requiring rope (describe rigging, rope length, pit depth, quality of bolts)_____________________________________
Other:____

Formations

<u>Calcite</u>
Flowstone_______________________________________
Stalactite Deflected________________________________
Soda Straw_______________________________________
Stalagmite_______________________________________
Column____
Popcorn____
Boxwork____
Calcite coating____________________________________
Calcite crust______________________________________
Drapery____
Helictite____
Heligmite_______________________________________
Cave pearl(s)_____________________________________
Calcite rafts______________________________________
Rimstone dam (s)__________________________________
Spar____
Shield____

<u>Aragonite</u>
Stalagmite_______________________________________
Stalactite____
Other:____

<u>Gypsum</u>
Crust____
Flower____
Cotton/Hair_______________________________________
Rope____
Needles____

<u>Hydromagnesite</u>
Balloon____
Moonmilk_______________________________________

Notes:____

Geology I

<u>Bedrock (Structural)</u>
Faults (strike/dip)________________________________
Folds____
Slickensides ___________________________________
Joints (strike/dip)________________________________
Styolites____

<u>Bedrock (Sedimentary rock characteristics)</u>
Cross bedding___________________________________
Bedding planes (well defined)_______________________

Distinctive bedding contacts________________________
Oolites________________________________
Chert nodules________________________________
Chert layers/beds____________________________
Shale beds________________________________
Sandstone beds______________________________

Cave Sediments (when possible note thickness in inches or feet)

Paleo

Clay/Mud________________________________
Mud cracks________________________________
Ripple marks________________________________
Consolidated sand/gravel______________________
Quartz pebbles______________________________
Interbedded sand/gravel/mud___________________
Organic debris______________________________

Recent

Clay/Mud________________________________
Mud spatter cups____________________________
Mud cracks________________________________
Ripple marks________________________________
Sand________________________________
Gravel________________________________
Sand/gravel________________________________
Quartz pebbles______________________________

Interbedded sand/gravel/mud___________________
Cobbles________________________________
Organic debris______________________________
Rock flour________________________________
Other________________________________

Geology II

Manganese

Coating________________________________
Dendrites________________________________

Solution/Corrosion Features

Scallops________________________________
Rillenkarren________________________________
Ceiling pendants____________________________
Ceiling/wall cusps___________________________
Corrosion residues___________________________
Fluted walls/ Vadose grooves___________________

Corrosion Features

Potholes________________________________

Fossils

Horn coral________________________________
Colonial Coral______________________________
Brachiopods________________________________
Bryozoans________________________________
Crinoids________________________________
Blastoids________________________________
Cephalopods________________________________
Gastropods________________________________
Fossil hash________________________________
Bones________________________________
Teeth________________________________
Other________________________________

Notes:________________________________

Biology

Vertebrates
Bat
Bat bones
Bat guano
Bat scratches
Bones (specify if possible)

Mammals
Reptiles
Amphibian

Birds (specify if possible)

Other

Invertebrates
Amphipods
Beetles
Centipede
Crickets
Diplurans
Isopods
Harvestman
Millipede
Springtails
Spider
Other

Microbial Colonies
(color/size)

Notes:

Cultural/Archaeological

Artifacts

Charcoal

Pictographs

Petroglyphs

Mud glyphs

Signatures (historic)

Graffiti

Other

Notes

Glossary

abiotic — of the physical and not the biological. Lacking living components.

accidental — any animal accidentally living in a cave, usually by falling in or being washed in or otherwise taken in, not on it's own account.

adaptation — the process of making adjustments in response to the environment.

aquatic — describes a surface or underwater habitat and the animals that live in or on it.

aquifer — a zone of the earth saturated with water.

artifact — an object produced by human workmanship.

bat — the only mammal that can fly, known for its use of echolocation to move and hunt in the dark.

bat gate — a gate constructed at the entrance of a cave or mine, designed to prevent humans from entering while permitting free entrance and exit of bats, other creatures and natural airflow.

bed — a depositional layer of sedimentary rocks or unconsolidated sediment.

bedding plane — the surface between two contiguous layers of rock.

biospeleology — the study of cave life, usually cavernicoles.

breakdown — a large or small accumulation of rock filling all or part of a cave passage after the collapse of part of the walls and ceiling.

calcite — a mineral ($CaCO_3$) composed of calcium carbonate; the principal component of limestone.

calcium carbonate — a compound ($CaCO_3$) found in nature as calcite; in shells, limestone, and used in making lime and cement.

carbonic acid — a weak acid (H_2CO_3) formed by water reacting with CO_2, especially in the soil.

cartography — the science and art of making maps. Modern cavers survey caves as they explore them and later draft maps from these surveys.

cave — a natural subterranean chamber or passage that extends at least in part into total darkness and is big enough to be entered by people. Usually formed by the solution of carbonate rock in karst but can also be formed by other natural mechanical processes in non-karst topography. It is also used as a verb suggesting, “to explore a cave”.

Cave Research Foundation (CFR) — a national organization formed to promote cave science, which usually works in conjunction with government agencies on public lands, particularly the National Park Service.

caver — a person who may visit caves for purposes of recreation or for basic research activities including exploration, mapping, and photography and who generally enjoys caves. Less commonly known as a spelunker.

cavern — an underground chamber often of large size. See cave.

cavernicole — an animal (usually invertebrates) living all or part of its life in a cave.

chert — a hard smooth rock ranging from white to black, also referred to as flint, often found in layers of limestone. This rock was often used for tools and as a fire starter by Native Americans and pioneers.

chiroptera — "hand-wing;" the scientific order that bats belong to.

column — a cave formation (speleothem) formed when stalactites and stalagmites grow together, or when one of them grows all the way to the floor or ceiling.

commercial cave — see show cave.

doline — A closed depression or sink usually in a karst terrain. Also called a bling sinkhole or simply a sinkhole (lacking any opening or entry of surface flow).

dolomite — a limestone or marble rich in magnesium carbonate. The mineral CaMg(CO3)2.

dome — a vertical shaft in a cave as viewed from the bottom; formed by water dripping or flowing straight down through vertical cracks. See pit.

disappearing stream — in a karst region, a river or stream that flows into a sinkhole or crack and from there into an underground or cave river system.

discharge zone — the area where water emerges. In a cave, the discharge come out of a spring where ground water emerges as surface water into a stream, lake, or ocean.

dissolve — to cause to pass into solution, to separate into component parts. Carbonic acid dissolves limestone by separating the calcium and carbonate and creating a liquid.

drapery — a speleothem which forms when drops of water run down along a slanted ceiling; also known as "bacon."

dye tracing — the process used by scientists to track the path and speed of water through a cave. Environmentally safe dye is put into streams and sinkholes; then water in the cave and at discharge areas is tested for the presence of dye and noted for the speed at which the dye moved through the system.

echolocation — the ability of an animal to orient itself by receiving the reflection of sounds it produces, such as with bats.

ecology — the study of the interrelationships of organisms and their environments.

endemic — a plant or animal native to a specific area and habitat and found no where else. Examples in GRSM: Stygobromus fecundus in Gregory Cave.

endangered species — an animal or plant species whose population has decreased to the point where it is in danger of disappearing forever. Also a federal or state legal term noting an animal with special protections.

entrance zone — the interface between the surface and subterranean environments leading into the cave to the twilight zone.

epigean — pertains to the environment and its components on the surface of the earth or above-includeing streams. Opposite of subterranean.

epikarst — referes to the upper or outer most layer of well drained karstified carbonate rock immediately below the soil.

erode — to wear away by the action of water, wind, or glacial ice.

erosion — the action or process of eroding. While weathering separates materials and breaks them down, erosion transports materials to a new location.

evaporation — changing of liquids into a gas.

extinction — the process by which an animal or plant that once existed can no longer survive and then can not be found alive anywhere on earth.

extirpation — the process by which an animal or plant that once lived in a region can no longer survive in that region and can no longer be found there; usually due to mans direct removal, habitat destruction, or pollution.

fenster (karst fenster or geologic window) — geomorphic feature formed from the erosion of the overlying geology (nappe) revealing the younger underlying rock. The older rock is left remaining as a near complete rim around and over the younger rock (examples are Cades Cove, Tuckaleechee Cove, and Wear Cove, TN).

flint — see chert.

flowstone — a speleothem formed when water flows down walls, over floors, or over older formations depositing calcite.

food chain/web — a series of plants and animals linked by their food relationships; for example: a plant, a plant-eating insect, and an insect-eating bat would form a simple food chain.

fossil — a remnant, impression, or trace of an animal or plant of past geologic ages that has been preserved in the earth's crust.

geology — the study of the history of the earth and its life, especially as recorded in its rocks.

groundwater — water that infiltrates the soil and is stored in slowly flowing reservoirs (aquifers); used loosely to refer to any water beneath the land surface.

guano — the rich manure of bat dung.

gypsum — a sodium calcium sulfate mineral ($CaSO_4 \cdot 2H_2O$), colorless, white, or yellowish, found in powder or crystal form. Used for plaster, cement, and medicinal purposes; thought to be mined by Native Americans.

habitat — the place or type of site where an animal or plant naturally or normally lives and grows; the arrangement of food, water, shelter, and space suitable to an animal's needs.

helictites — speleothems that grow as small, twisted structures that project at varying angles often gravity defying.

hibernacula — places where bats or other animals hibernate, or sleep, during the winter to conserve energy.

karst — an irregular limestone region with sinkholes, disappearing streams, underground streams, and caves.

karstic — pertaining to karst.

limestone — a rock that is formed chiefly by accumulation of organic remains (shells or coral), consists mainly of calcium carbonate ($CaCO_3$); frequently contains fossils. The primary rock found in caves worldwide.

mesocavern — all areas within the subteranean large enough to be accessed by a person. Scientifically cavities in rock greater than 20cm. in diameter.

micocavern — all areas in the subterranean, usually in karst environements, too small to admit human entry but is sufficiently sized to be habitate for much of the subterranean fauna. Often representing the epikarst area.

mineral — an inorganic (non-living) substance occurring naturally in the earth and having definite physical and chemical properties.

nappe — in geology, a large body or sheet of rock that has been moved, naturally, across the surface of a younger underlying rock.

National Speleological Society (NSS) — the national caving organization formed in 1941.

obligate — refers to any species unable to live outside of the cave environment. Often has adapted cave specific characteristics (pigment loss, reduced eyes, elongated antennae)

paleontology — the study of life from past geologic periods by examining plant and animal fossils.

passage — in a cave, the corridor created by water and rock falls.

pH — a scientific measure of hydrogen ion activity to determine the acid or base level of a substance.

phreatic zone — area usually below the water table where voids in the rock are completely saturated with water.

pit — in a cave, a vertical shaft as viewed from above, formed by dripping or falling water through a vertical crack. See dome.

popcorn — a calcite speleothem with the appearance of popcorn.

pollution — the fouling of water or air with sewage, industrial waste, or other contaminants, making them unfit to support many forms of life.

pseudokarst — terrain resembling traditional karst including caves but lacking the karst solution process of soluble rock.

radon — a heavy radioactive gaseous element formed by the disintegration of uranium and thorium. It is colorless, tasteless, and odorless and found commonly in bedrock and sediments. All rocks and soil, including the limestone contain varying amounts of radon.

recharge zone — the area from which a body of water is recharged

resurgance — a spring whose water can be traced previous to inception or from within the karst landscape.

rimstone dam — thin mineral crusts formed at the edge of some cavern pools as calcite-rich water flows over the edge.

rimstone pool — a pool formed from the development of a rimstone dam.

saltpeter (also saltpetre) — a potassium nitrate compound converted from calcium nitrates often found and historically mined in dry caves and used in making gunpowder.

sandstone — a sedimentary rock made up of small pieces of rock, usually silicates such as quartz, that have been cemented together over time.

scallops — spoon-shaped hollows dissolved in the cave walls, floors, and ceilings by flowing water; the shape and size of the scallops tell scientists what direction the water was moving and how fast.

sediment — rocks or fragments transported by wind, water, gravity, or ice; precipitated by chemical reactions; or secreted by organisms.

sedimentary rocks — a rock formed of fragments transported from their source, usually by water. The sediments are usually laid down in layers. Sandstone and limestone, the two major rocks found at Mammoth Cave, are both sedimentary.

shaft — a vertical passage in a cave formed by water dripping or flowing through vertical cracks in the bedrock.

shale — a sedimentary rock formed by the consolidation of fine particles of clay, mud, or silt. Sometimes known as mudstone or siltstone.

show cave — a cave developed for public use, usually with paths, electric lights, stairways, or other conveniences. Also known as commercial caves.

sinkhole — a surface depression with gently sloping walls, which is an aspect of karst topography and which is formed by and acts as a conduit for water entering a cave system.

soda straws — speleothems that grow on cave ceilings as thin-walled hollow tubes. They are formed by water flowing inside the tube and depositing rings of calcite around their tips.

speleology — the scientific study of the cave environment, including the physical, chemical, and biological aspects.

speleothem — cave formations: secondary mineral deposits formed in caves, caused by the dissolution of minerals (such as calcite) and their subsequent deposition in crystalline form in growing layers in a variety of shapes.

spelunker — see caver.

spring — a natural flow of water from the ground, often the source of an above-ground stream or extensive aquatic subterranean system.

stalactite — a common speleothem which hangs down from the ceiling.

stalagmite — a common speleothem which rises up from the caved floor from calcite dripped from the ceiling.

stewardship — related to the environment, the concept of resposible care-taking; based on the premise that we do not own the resource, but are managers of the resources and are responsible to future generations for their condition.

stringer — A narrow vein or irregular filament of minerals traversing a rock mass.

stygobiont — the original term used to describe obligate aquatic cave life. Recent definition covers ALL aquatic cavernicoles including accidentals (see stygobite, stygophiles, and stygozenes).

stygobite — an obligate aquatic cave species. The aquatic equivalent of the troglobite.

stygophile — aquatic cave species which can live its life cycle both completely in the subterranean or epigean environment. It usually lacks any traditional cave adaptations. The aquatic equivalent of the troglophile.

stygoxene — a habitual aquatic cave species which must spend some portion of its life cycle in a cave and may return to the surface only for food. The aquatic equivalent of the trogloxene.

subterranean — pertaining to the underground environment in a karst or similar environment.

sump — a point in the cave where water meets the ceiling and airflow is stopped.

survey — For the purposes of this plan, survey refers to the mapping of caves and cave passages. This involves documenting passages using high quality instruments, which make known the azimuth, inclination, and measured distance along imaginary lines in the cave passage. This information is combined with a drawing of the cave passage, and created to scale using the gathered information and standardized symbols in a cartographic process to produce a map.

swallet — a stream or body of water at the point at which it enters a cave or cave system (or generally into the karst system). This often occurs in a sinkhole.

troglobite — an animal that lives its entire life within a cave and is specifically adapted to life in total darkness (some by losing their eyes or lacking pigmentation (color)). Examples: isopods, amphipods and flatworms in Gregory Cave.

troglophile — animals that can live all their lives either inside or outside a cave. Examples: salamanders, springtails, and spiders.

trogloxene — an animal that spends part of its life in caves, but must venture out for food. These animals bring organic materials important to troglophile and troglobite survival into the cave. Examples: Bats, bears, crickets.

twilight zone — the part of a cave near the entrance where light penetrates but does not receive direct sunlight, extending to the zone of absolute dark. An important habitat for many trogloxenes.

uvala — A complex closed depression formed by the coalescence of several lesser or smaller depressions, sinks, or dolines within its rim.

vadose zone — the zone within the cave where water flows in an unsaturated environment. Characterized by in-cave streams or water percolation within the air filled environement.

vandalism — the willful or malicious destruction or damage of any public or private property.

watershed — an area of land where all water collects and drains into a common body of water (such as a river or lake).

water table — the upper level of the underground reservoir of water; the level below which the ground is saturated.

weathering — the action of the elements in altering the color, texture, composition, or form of exposed objects, removing material physically or chemically. Water, wind, trees, and chemicals can cause weathering. At Mammoth Cave, the limestone is weathered by carbonic acid.

wild cave — a cave in its natural state, not developed for public use, in contrast with show caves.