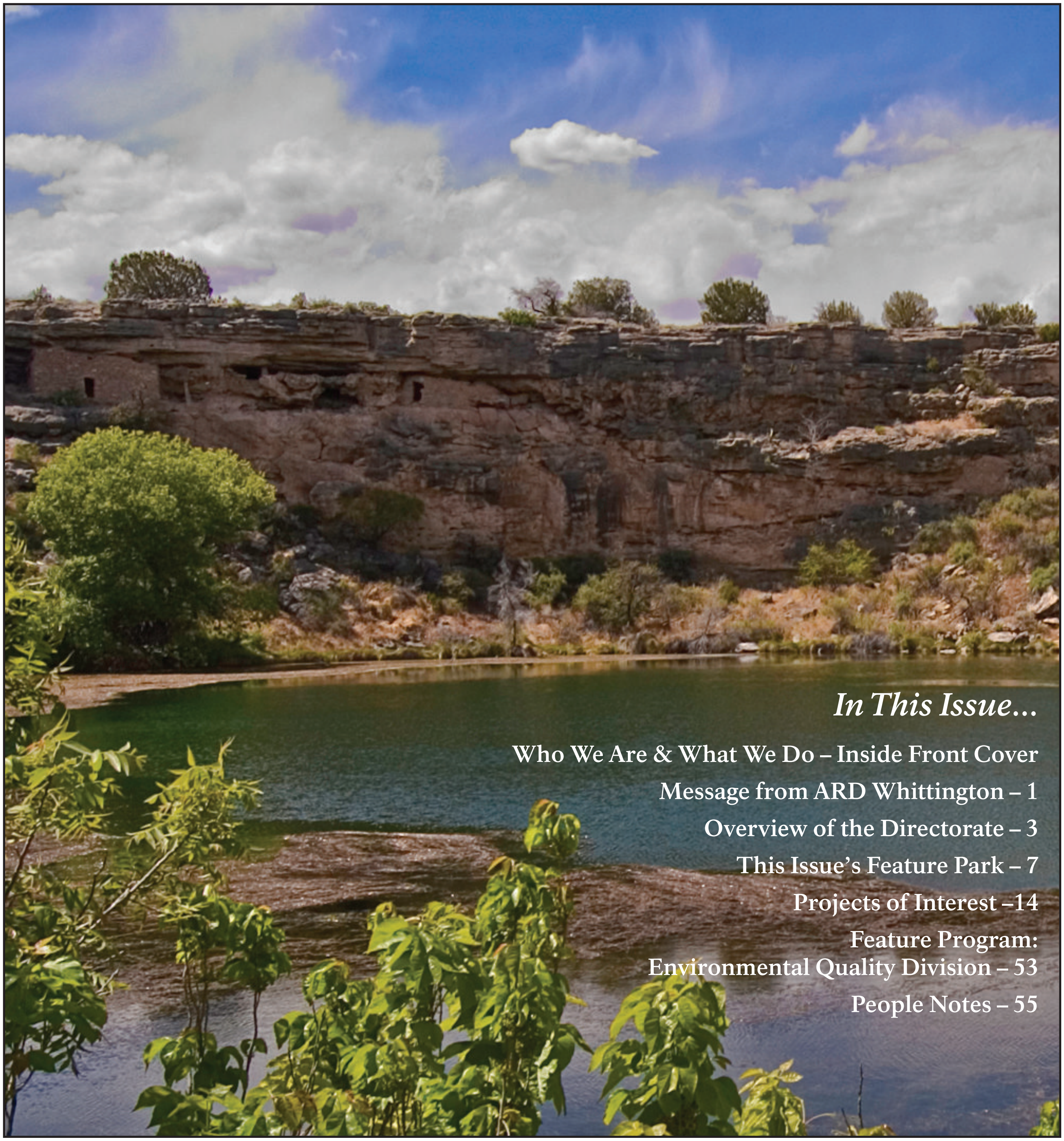
Intermountain Region
Resource Management

National Park Service
U.S. Department of the Interior

CROSSROADS IN SCIENCE

Where the Intermountain Region's Resource Stewardship and Science Programs and Centers Meet

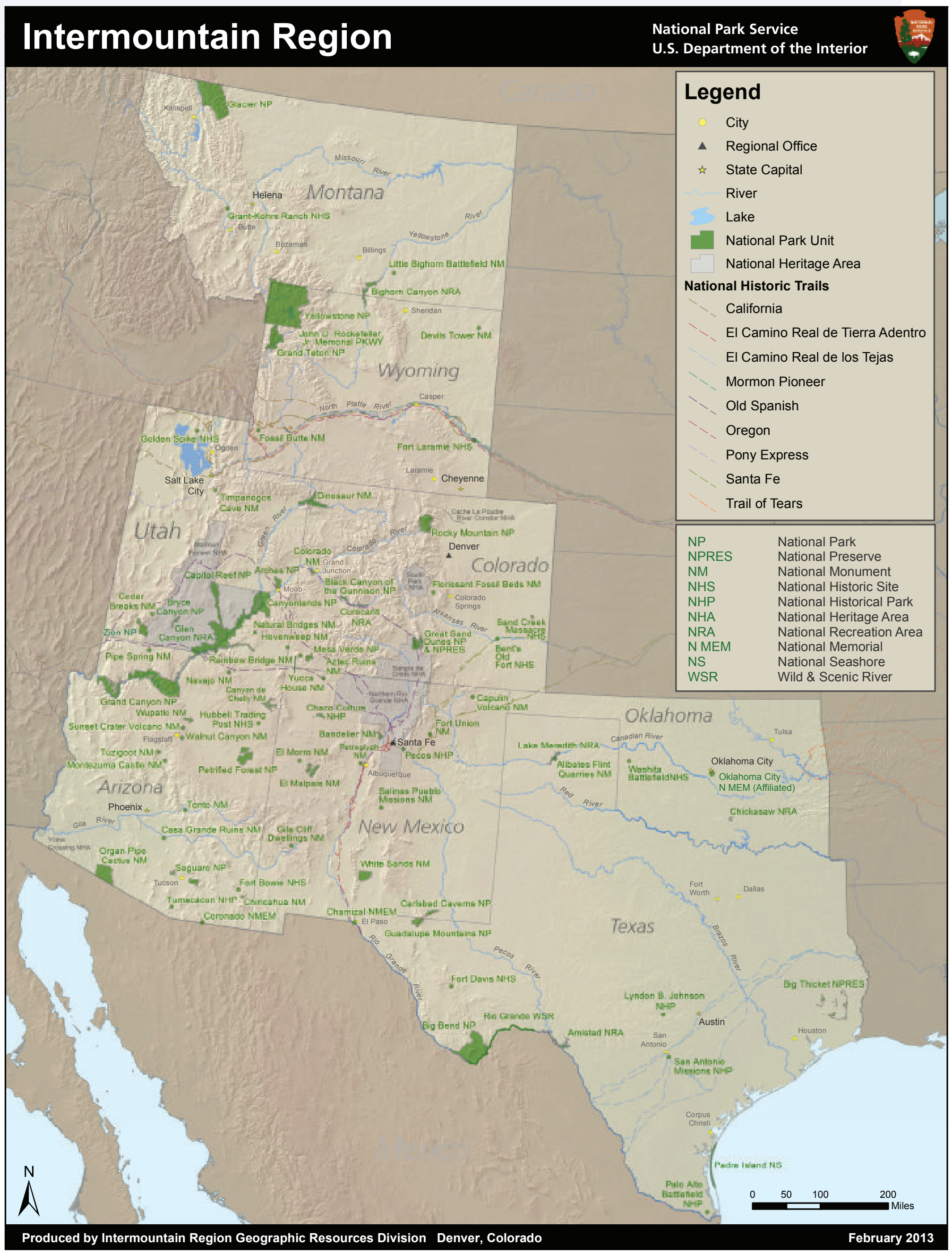
Fall 2013



In This Issue...

Who We Are and What We Do

The Resource Stewardship and Science Directorate provides technical expertise and administrative assistance to 91 parks and about 6,000 employees in the National Park Service's eight-state Intermountain Region (IMR). The region covers Montana, Wyoming, Colorado, Utah, Arizona, New Mexico, Oklahoma and Texas. It is the park service's largest region, and its parks encompass more than 11.1 million acres. The directorate is one of five directorates in the IMR's headquarters in Lakewood, Colorado. The office provides specialized help in policy, budget, program development, workforce development and communications so that its parks can best serve visitors. A brief description of the Resource Stewardship and Science Directorate's programs begin on page 3 of this issue.



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Feature Park — Montezuma Castle National Monument
See the Submerged Resources article on diving in Montezuma Well on page 7.
Photo Credit: Brett Seymour

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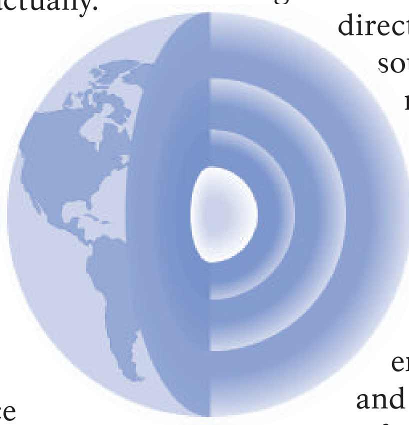
Looking West,
Montezuma Castle National Monument

Introduction from Associate Regional Director Whittington

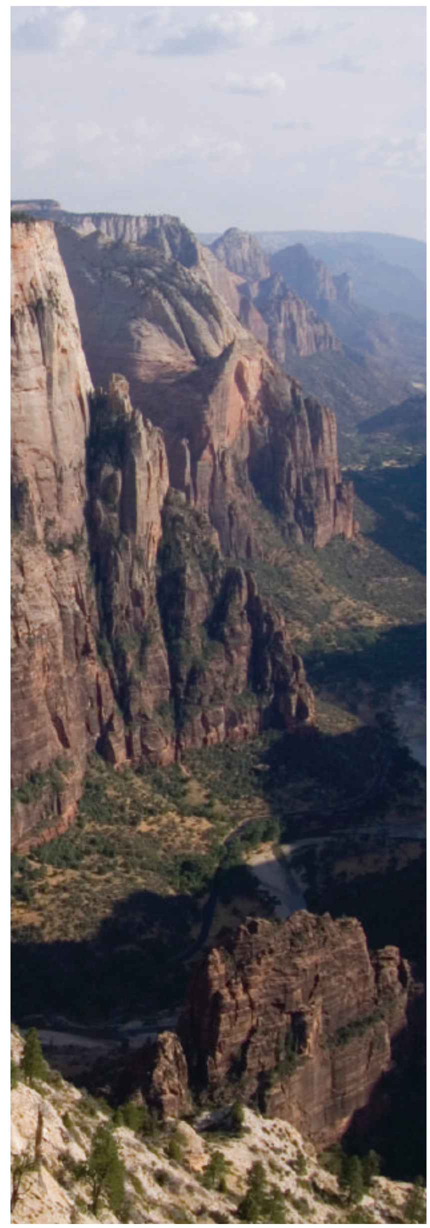
Welcome to Crossroads in Science, a new publication of the Resource Stewardship and Science Directorate of the National Park Service's Intermountain Region (IMR).

Welcome again, actually. The Crossroads name has graced IMR resource publications before. It was "born" in 2005 as Cultural Crossroads, a newsletter for what was then Cultural Resource Management, CRM for short. As the Intermountain Region's resources programs broadened and combined, the newsletter evolved in 2009 into Crossroads, to serve the IMR natural and cultural resource divisions in the Resource Stewardship and Research Directorate. With our continued growth and most recent reconfiguration into the Resources Stewardship and Science Directorate, one more revision of the name is only fitting: Crossroads in Science, where the Intermountain Region's resource stewardship and science programs and centers meet.



What has not changed, however, is the core Crossroads mission and aim: to present, explain and share the work, the technical expertise and the wide-ranging reach of this most diverse of Intermountain Region directorates. The directorate supports sound resource management decisions for 91 IMR parks in eight states, with more than 6,000 full-time and seasonal employees and a combined area of more than 11.1 million acres.

Working together under this directorate is a remarkable array of disciplines and programs: Natural Resources, Cultural Resources (including the Western Archeological and Conservation Center in Tucson and NPS Vanishing Treasures program), Environmental Quality, Landscape Conservation and Climate Change, Colorado River Management, Planning and Special Projects, Geographic Resources (GIS), and the service-wide NPS Submerged Resources Center, which calls the IMR home. Also working



Zion National Park

with us: the Great Northern Landscape Conservation Cooperative (Bozeman), and three Cooperative Ecosystem Studies Units: Rocky Mountains CESU (Missoula), Colorado Plateau CESU (Flagstaff) and Desert Southwest CESU (Tucson).

The interests and subject matter of Crossroads in Science articles this year and in the years to come will range across all these fields and programs, with an emphasis on their application among the parks of the Intermountain Region. This issue, for instance, includes articles on a Submerged Resources project at Montezuma Well in Arizona's Montezuma Castle National Monument, Vanishing Treasures work at Utah's Zion National Park and Golden Spike National Historic Site, and a cave mapping project at New Mexico's El Malpais National Monument. There also are articles on topics that range across parks and disciplines, connecting parks to larger landscapes around them and promoting resilience of park resources against forces such as climate change. One such article, for instance, deals with developing partnerships and strategies to promote climate change adaptation.

Crossroads in Science seeks to demonstrate the work that Intermountain Region programs, parks and people do every day in resource stewardship and science. It will display IMR's commitment to excellence in science, research, and sound resources management for the depth and breadth of our commitment to and care for the richly diverse natural and cultural resources of the Intermountain Region and its parks. We hope it also will become a bridge

SRC Deputy Chief Brett Seymour talks to the Mt Carbon Elementary School second grade in Littleton, Colorado about SCUBA diving and underwater cameras.

the directorate's "customers" – IMR parks and park collaborators; cooperating institutions and organizations; resource teams in other NPS regions; federal, state and local government partners; and the broader audience of park visitors and the American public. Thus, it aims to appeal to both scholarly science and accessible public interests in its articles and other content.

In the coming years, we expect Crossroads in Science to show to collaboration with other regions of the Park Service.

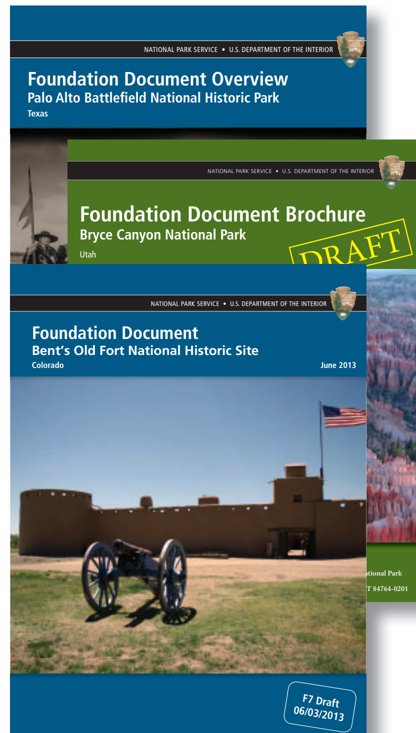
To our colleagues in resource stewardship and science, we invite your submissions for future issues. And to all, we invite your feedback. Join us here at the Crossroads in Science.

Tammy Whittington
Associate Regional Director,
Resource Stewardship
and Science Advisor

The IMR Resource Stewardship and Science Directorate at a Glance

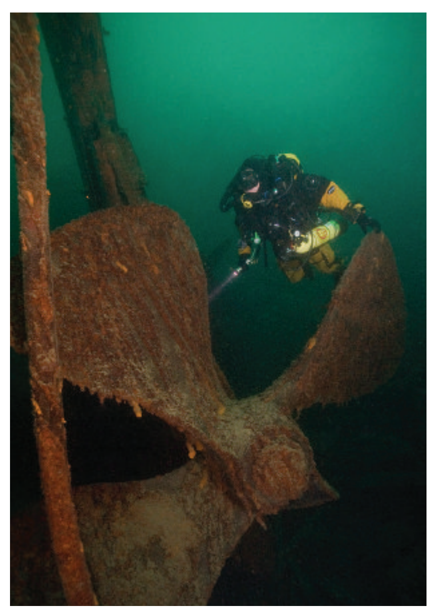
Planning

The IMR Planning Division's main purpose is to help parks make informed decisions about complex long-term management issues affecting park operations. It works with other NPS divisions to find the necessary staff, money and expertise to ensure that parks are ready to undertake construction or change their operations in ways significantly affecting visitor use. It works closely with the IMR's Environmental Quality division, the Washington office of Park Planning and Special Studies, and the national Planning Leadership Council to ensure consistency and compliance. A major focus of the department is to see that all IMR parks have a complete Foundation Document written by 2016, the NPS' 100th anniversary. Foundation documents outline a park's primary purpose and provide key guidance for future planning decisions.



NPS Submerged Resources Center

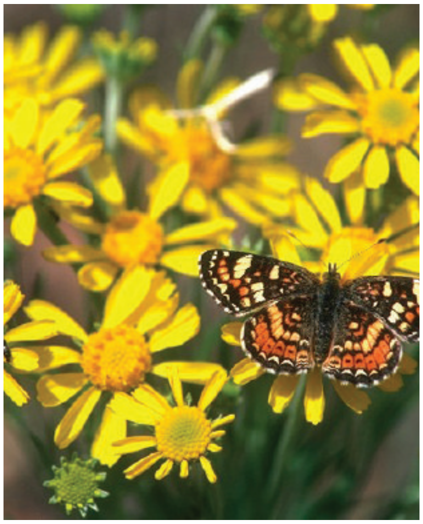
Many people might be surprised to learn that this internationally known underwater Center is headquartered in the IMR's high-desert plains. The Submerged Resources Center (SRC) assists parks with the documentation, monitoring and interpretation of underwater resources system-wide. Staffed by archeologists and photographers the center provides technical expertise to more than 130 parks that have cultural and natural resources in some 5 million acres of submerged bottomlands. The Center also produces shipwreck "trail" guides, visitor center films, and educational materials to improve park visitor experiences and understanding of submerged resources. In addition, it is the centralized office for the NPS dive program, and trains park divers in underwater search and recovery, crime scene investigation, maintenance, and specialized diving techniques.



Natural Resources

Natural resources include a wide of array of subjects, including wildlife, fisheries, exotic and invasive plants, air and water quality, energy, wilderness, minerals, oil and gas management, natural sounds and night skies. This program provides professional and technical services to IMR parks in these areas, and also supports the National Natural Landmarks Program. Staff serve as liaisons with other federal and state agencies, and participate in large-area/ecosystem planning. Research and technical assistance in natural, cultural and social sciences are provided through academic partners by the program's Cooperative Ecosystem Studies Units (CESUs).

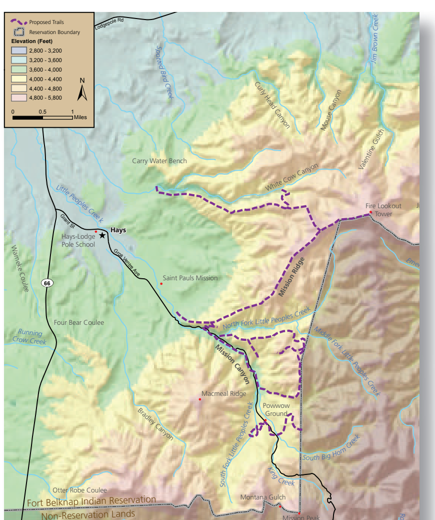
Environmental Quality



Complying with the nation's environmental laws and regulations can be a complex, time-consuming task. But this program helps parks find their way through laws such as the National Environmental Policy Act (NEPA) and Section 106 of the National Historic Preservation Act (NHPA). The program also conducts internal scoping meetings and environmental screening; develops strategies for public involvement, facilitation and comment analysis; prepares documents; and conducts formal training. In addition, it helps parks review documents prepared by other federal, state and county agencies.

Cultural Resources

Preserving the region's precious objects, documents and memories is one of the IMR's major missions. The Cultural Resource program helps accomplish these objectives by providing consultation, training and technical assistance to parks in archeology, history, historic preservation, cultural landscapes and museum and library services. For example, many of the area's most-unique artifacts are stored in the program's Western Archeological and Conservation Center, a state-of-the-art facility in Tucson, AZ that's also a research center for NPS staff and researchers from around the world. Ancestral sites and ties to living communities are also protected and maintained in the Intermountain region though the program's Vanishing Treasures programs. Vanishing Treasures also helps preserve "Park rustic" and Western vernacular architecture, working from the Western Center for Historic Preservation at White Grass Ranch in Grand Teton National Park.

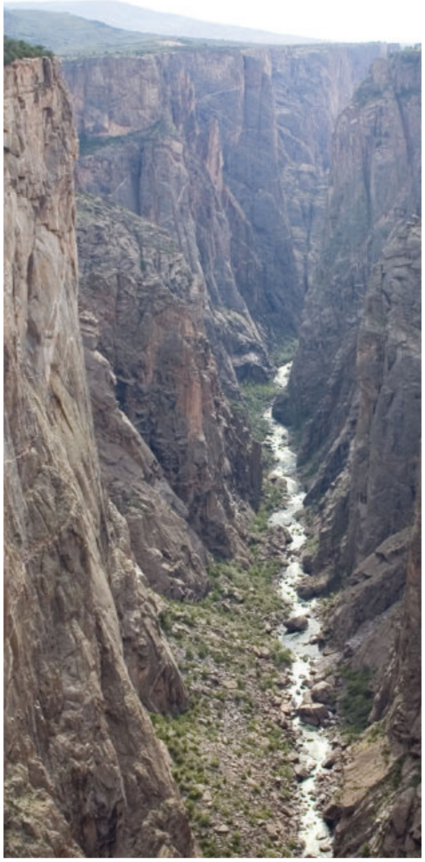


Geographic Resources

Understanding exactly what and where things are is critical to resource management in IMR parks. This program helps put things like natural landmarks and historic buildings on the map—literally—by deploying diverse geospatial tools, including Geographical Information Systems (GIS), remote sensing, Global Positioning System (GPS), and cartography. The program supports and advises parks in hardware/software and licensing, as well as with data collection and management, including the use of aerial photography and LiDAR, the light detection and ranging tool useful in contour-mapping. The program also provides online services supporting better management of parks' mapping data and effective distribution of that information to other parks, programs, agencies and the public.

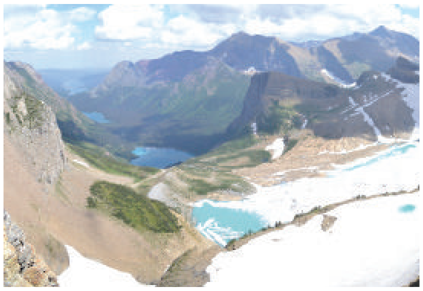
Colorado River Basin Coordinator

Managing park resources in the Colorado River Basin is tricky, yet essential to the IMR's mission. The Colorado River and its tributaries flow through or near 11 national parks in the IMR, including the Grand Canyon, Glen Canyon, Black Canyon of the Gunnison, Canyonlands and Dinosaur National Monument. The system's water dramatically shapes the arid landscape and affects plants and wildlife. But it's also one of the most highly managed and studied river systems in the world, supplying water and electricity to tens of millions people. Through its Colorado River Coordinator, this program's goal is to help the IMR develop an ongoing river-management strategy designed to preserve and protect park resources without unduly impinging on the needs and responsibilities of the federal, state and private organizations that also have a say in the basin's supervision.



Landscape Conservation and Climate Change

An array of forces can degrade parks: climate change, mining or oil and gas development, habitat fragmentation, and the rapid spread of invasive non-native plants and animals. This program helps parks cope with these issues using science and partnerships with other agencies and the public. It co-leads the Great Northern Landscape Conservation Cooperative and coordinates the region's participation in Landscape Conservation Cooperatives and Climate Science Centers. The program helps parks predict and mitigate the effects of climate change and other large-scale events, and collaborates with other programs to create a regional strategy for landscape conservation.



—NPS Submerged Resources—

Feature Park—Montezuma Castle National Monument

Montezuma Well: Exploring Inner Space in the Intermountain Region

By John Bright, Archeologist , NPS Submerged Resources Center
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ABSTRACT: Since 1980, the Submerged Resources Center (SRC) has worked toward a single goal: the protection, preservation, public access and interpretation of submerged resources in national parks and beyond. Through the years, the center has achieved this by using innovative scientific techniques to access, observe, document, and research submerged resources nationwide. The Intermountain Region is home to several fascinating geological and man-made bodies of water that are host to a wide (and sometimes bizarre) array of natural and cultural resources. One such location is Montezuma Well, a part of Arizona's Montezuma Castle National Monument. NPS archeologists visited the Well several times beginning in 1979 and culminating with a multi-faceted research expedition in 2006. Using remotely operated vehicles (ROV's), closed-circuit rebreathers and chemical probes, SRC researchers explored the captivating depths of the Well. This expedition shed new light on a mysterious and unique National Park Service resource.

Situated in the heart of Arizona's Verde Valley, amidst its arid Mogollon Rim and Black Hills, Montezuma Well is a most peculiar place. Under a perennially blazing sun, this mysterious oasis, a perpetual source of water in a dry climate, has mesmerized, awed, and amazed those who have happened upon it for thousands of years. The Well is a large and open window into the karst bedrock that underlies this dusty landscape and it is a focal point for the extensive

Montezuma Well, 2006. Red object, center, is an SRC dive buoy.
NPS photo by Brett Seymour

H.J. Charbonneau's dive. Note compressor and air reservoir in support boat. NPS photo by Park Custodian (Superintendent) Homer Hastings

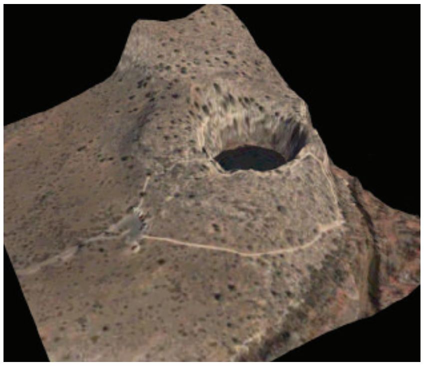
H.J. Charbonneau during his exploration of Montezuma Well in 1948. He dove using surface-supplied air, not scuba (note air hose and dive mask).
NPS photo by Homer Hastings

Native American cliff dwellings that lie around its waters high in the nearby rock faces. Together, these amazing natural and cultural features comprise a portion of Montezuma Castle National Monument. The Well's very existence in its dry desert surroundings testifies to its uniqueness, but location is only part of what makes Montezuma Well so fascinating. The Well's earliest underwater explorers (it was first visited by divers in 1948) discovered that the Well's inner workings are stranger than its position atop a valley in the Arizona desert. In the decades that followed, teams of divers gradually shed light on its mysteries. Yet it was not until the 2006 expedition, when the SRC brought expert divers and state-of-the-art equipment to Montezuma's Well, that the world got its first real glimpse into the heart of the mystery.

According to Montezuma Well historian and Park Ranger Jack Beckman (see Beckman 1990), a volcanic lava flow filled the Verde Valley approximately 12 million years ago. As the lava flow settled, it dammed an ancient river, which created a lake. Over the next few million years, the lake filled with sediments that eventually settled and hardened, forming a thick layer of limestone in place of the former lake. In some parts of the valley, this layer of limestone is nearly 2,000 feet thick. Over millennia, streams of slightly acidic water running off the surrounding mountains slowly etched and eroded paths through this layer, leaving ridges of hard rock behind. Meanwhile, as the water passed over the limestone, it dissolved into, and then percolated through, the rock to create a network of subterranean passages in a manner similar to the formation of the vast underwater caves in northern Florida and the Yucatan Peninsula of Mexico.

This kind of gradual infiltration of water through softer limestone typically transforms small passageways into large caverns and caves. In some cases – including at Montezuma Well – the subterranean opening finally grows to the point that the "roof" or "ceiling" can no longer stay up on its own. The structure collapses beneath the weight of the limestone above, forming a sinkhole – and this water-filled sinkhole opens a window into the aqueous arteries beneath the Earth's surface.

In this way, Montezuma Well is a geological formation more typical of northern Florida where a large karst bedding



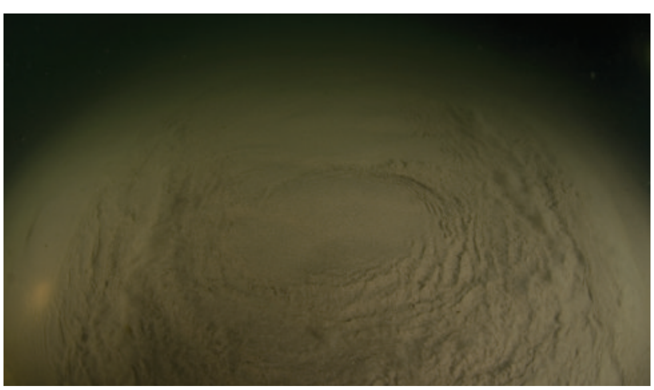
GIS image with photo laid over topography shows Montezuma Well, looking northeast.
NPS image by Dave Conlin

plane evolved into hundreds of underwater caves, yet is virtually alien to arid central Arizona. The Well's water rises from a source in the bottom of the pool, which is linked to the area's larger, more diffuse aquifer. Beckman estimated the Well had a capacity of approximately 15 million gallons. The springs supplying Montezuma Well maintain a stable depth and temperature, and a small cave called a "swallet" at water level allows the water to drain into nearby Beaver Creek at a rate of 1,100 gallons a minute.

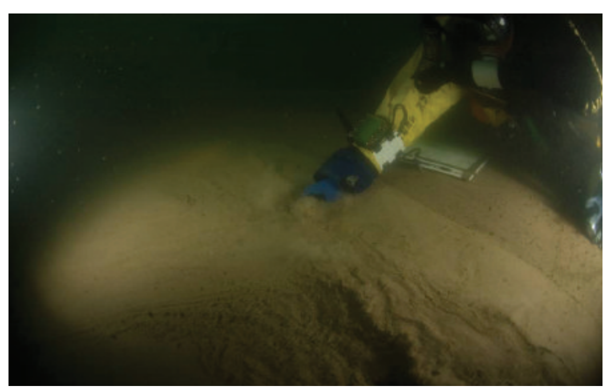
GIS image shows Montezuma Well with contour elevations in meters. Lighter-colored lines looping below the well are the park trail. Dark line across lower right is Beaver Creek. NPS image by Dave Conlin

When explorers began diving into the Well, however, they found a strange phenomenon: sand "boiling" up in two pools from the spring that feeds the Well from below. Dubbed a "false bottom" by SRC archeologist Daniel Lenihan (see Lenihan and Conlin 2006), this occurrence has been variously referred to as "quick-sand," "volcanic-like flow of silica gel" and "boiling oatmeal" by teams of divers who have explored Montezuma Well over the past 50 years. With no similarly analogous geological phenomenon in the Florida caves for comparison, these boiling pools confounded the divers. It seemed clear that the key to unlocking the mysteries of the site and its natural and cultural history would be the extent, composition, and characteristics of the Well's bottom.

At the request of Montezuma Castle Superintendent Kathy Davis, the SRC in 2006 mounted an expedition to map the Well's underwater areas and sample the physical properties of the "false bottom." Over the course of the four day project, SRC divers



The fluidized sands of the "false bottom" are in constant motion in both the east and west sand pools. The sands seemed to be churning counter-clockwise. NPS photo by Brett Seymour

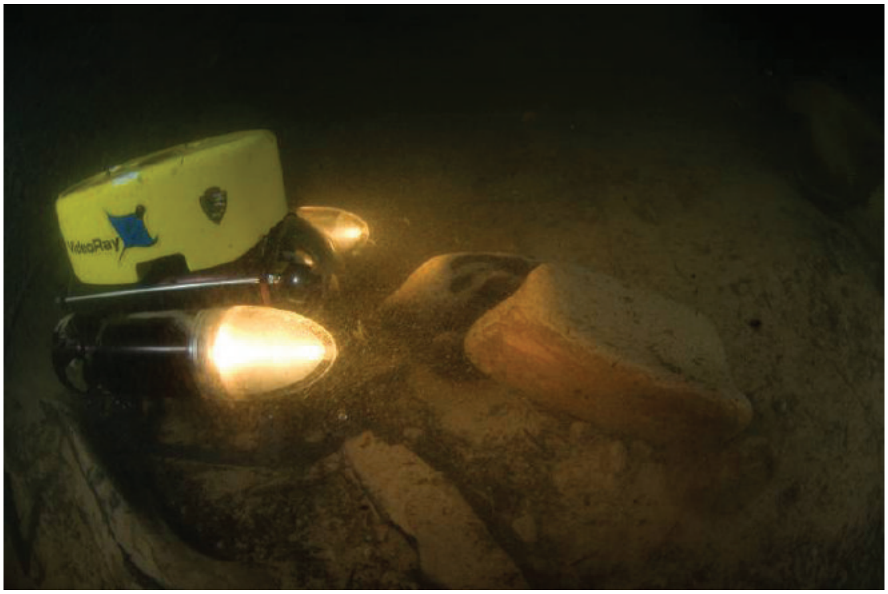


SRC Diver Dave Conlin's hand is motionless. The sands are rooster-tailing against his palm from their own flow. NPS photo by Brett Seymour and photographers captured imagery to help park managers, interpreters, researchers, the public, and the Yavapai Apache Nation — the tribe most closely linked with the site – better understand Montezuma Well.

To collect environmental data in the deep pool below the false bottom, the team used a YSI 600xlm multi-parameter environmental sonde (water testing probe) capable of real-time measurements of 14 physical and chemical properties of the water and particulates. The team also collected samples at the surface of the false bottom for third-party chemical analysis. Divers photographed using a combination of hand-operated still and video cameras in conjunction with a remotely operated vehicle (ROV), an unmanned camera piloted from the Well's surface. The ROV also was used underneath the false bottom, an area where diver safety was uncertain. Divers used traditional underwater survey methods — compasses, tape measures, writing slates, and surface buoys— to map the extent and location of various underwater features.

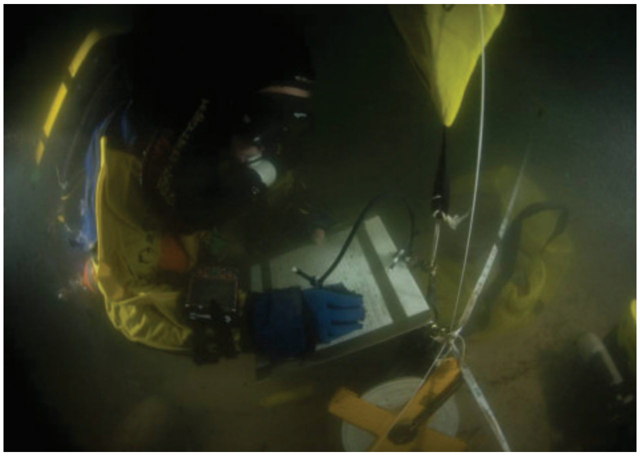
As in most underwater research, exploration of Montezuma Well required a multi-disciplinary approach. The distance between safe entry points and equipment staging areas added a logistical challenge to the operation.

Montezuma Castle National Monument Superintendent Kathy Davis tries her hand at operating the SRC's remotely operated vehicle (ROV). NPS photo by Brett Seymour



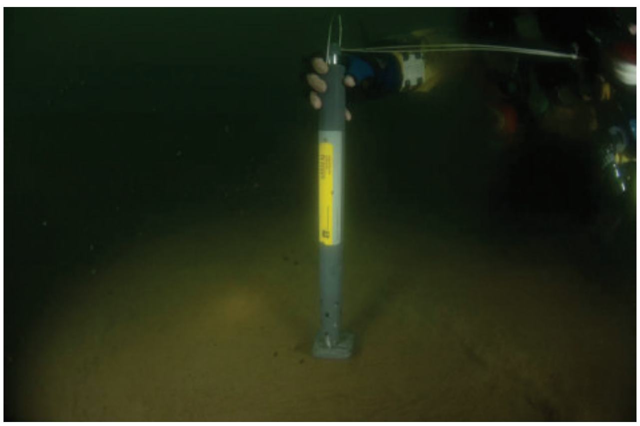
ROV sitting on Montezuma Well's false bottom. Some instruments and even rocks can be buoyed by the fluidized sand. NPS photo by Brett Seymour

Unlike working in the ocean, where divers stage and deploy from the deck of a boat, researchers at the Well had to hike across the rough terrain of the rim with their cumbersome underwater exploration gear. Nevertheless, in just four days the team of five divers collected a large amount of data. To map underwater features, a series of survey datums or reference points was established with surface buoys. Each buoy was marked via GPS, linking the datum and all measurements

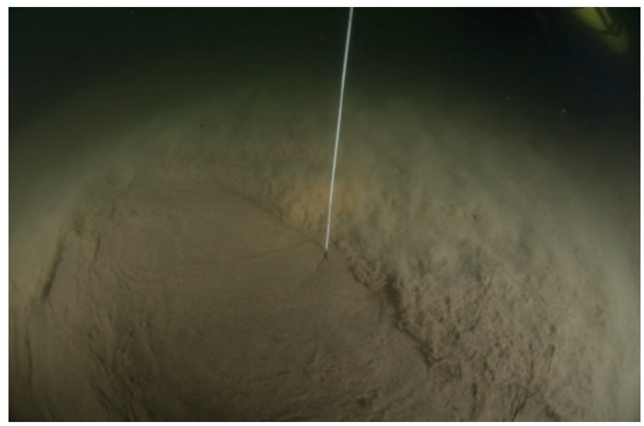


SRC Archeologist Dave Conlin mapping bottom features of Montezuma Well. NPS photo by Brett Seymour

SRC's Dave Conlin deploys YSI sonde probe through the sands of the false bottom. NPS photo by Brett Seymour



Probe with 3-pound weight is lowered into one of the sand pools. NPS photo by Brett Seymour



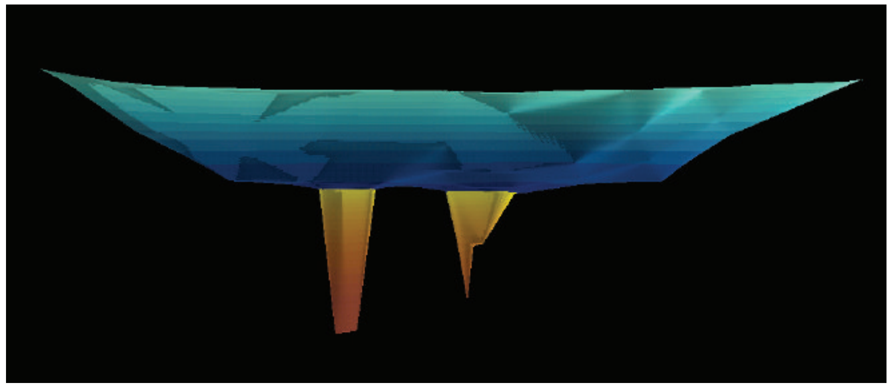
Probe is extended an additional 44 feet to the bottom of the west sand pool. NPS photo by Brett Seymour

to the real world. Underwater, the divers used tape measures and compasses to determine the extent of walls, ridges and pinnacles. They wrote down the measurements on waterproof recording slates.

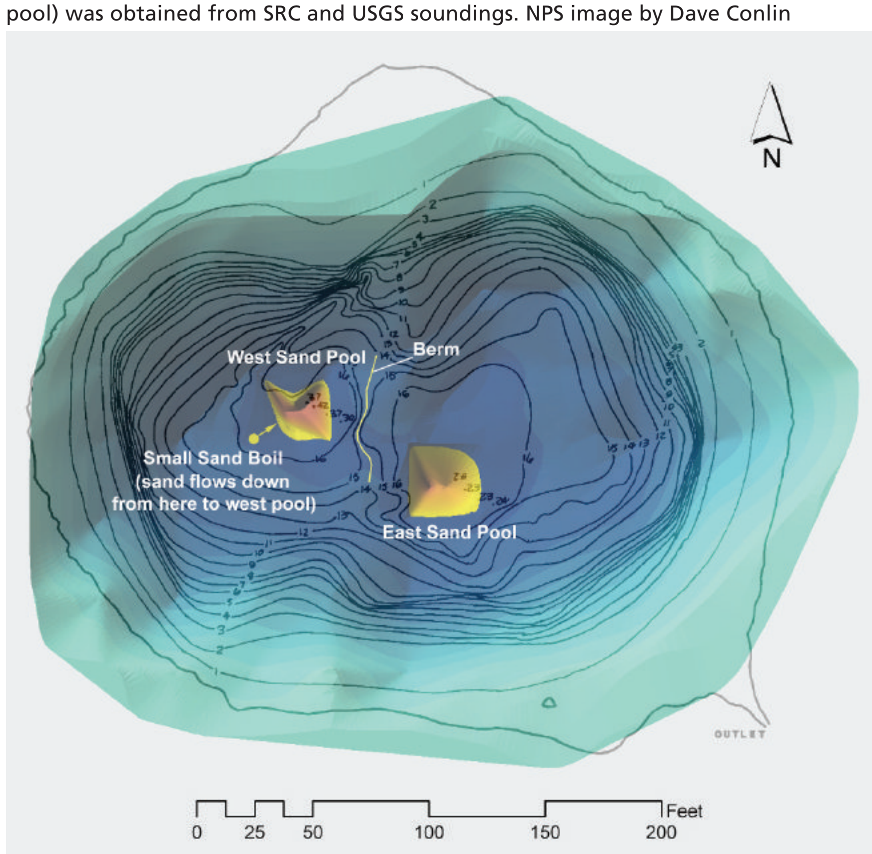
In previous expeditions, including an expedition by the U.S. Geological Survey (USGS) in 1991, spatial data had been collected in tidbits. Until the SRC study in 2006, however, none of those projects had compiled and incorporated that data into comprehensive maps of Montezuma Well and surrounding areas. SRC archeologist Dave Conlin combined the new study's field-collected measurements with the previous USGS data and publicly available digital mapping resources into a series of two- and three-dimensional maps using multiple data filters and GIS processing applications. The result was a comprehensive map of the interior of the Well, down to the false bottom at a depth of 55 feet. As divers were unable to penetrate the false bottom themselves, the SRC resorted to more clever methods to probe that area to determine the remainder of the spring.

Initial investigation of the false bottom revealed that it was most likely composed of a hyper-saturated mixture of suspended sand buoyed up by the hydraulic head of the spring at the bottom of the Well —material considerably more dense than water. Submersible pressure gauges, used to measure depth in water, generate their readings based upon ambient pressure, but they operate on the assumption of a constant density of the fluid in which that pressure is measured, in this case water. In a more dense fluid such as the false bottom's mixture of suspended sediments however, changes in depth register larger changes in pressure. Therefore, depth gauges calibrated for water would give inaccurate readings in the suspended sediment mix. Lacking specifically calibrated instruments, the dive team instead used a low-tech but effective method to take soundings: a weighted line. By using it repeatedly across the roiling pools of sand and water at the bottom of the Well, the depth measurements collected with the line would still reveal the topography beneath the false bottom where divers could not physically go. Moreover, they knew the relationship between pressure and depth so that they also could drop a weighted, water-calibrated gauge (the one on the YSI) through the false bottom. Then, by calculating the difference between the actual depth from the weighted line and the depth registered on a water-calibrated gauge (measured with the YSI sonde), they determined the exact difference in density between fresh water and the basin bottom sediment solution. Using this method, the team determined that the fluid in the false bottom was 1.72 times more dense than fresh water.

The resulting maps – incorporating the old USGS measurements and all the new measurements and soundings – revealed the complete size and shape of Montezuma Well: an even, elliptically shaped basin, sloping toward the bottom. In the center are two pools of churning sand and water, West and East – where fresh water and the false bottom meet at a



GIS image shows subsurface profile of Montezuma Well, looking from south to north. Depth of the fluidized sand pools (yellow-orange columns beneath blue water of well pool) was obtained from SRC and USGS soundings. NPS image by Dave Conlin



GIS image shows planimetric (horizontal features) view of Montezuma Well's pond depths, marked in meters. NPS image by Dave Conlin depth of 55 feet –with a slight ridge between them. The pools, however, are not the same size. SRC divers found that the West pool is deeper. It reaches from 55 feet water depth at its top to 123.75 feet at the bottom of the fluidized sand – that is, a total of 68.75 feet of fluidized sand beneath the "false bottom." The East pool measures to an overall depth of 74.2 feet – 55 feet of water above the false bottom and 19.92 feet of fluidized sand below.

Combining all of the measurements, the team created a comprehensive series of detailed maps. Besides documenting the extent of Montezuma Well, the SRC also sampled the material composing the false bottom — the fluidized sand emulsion — for analysis, and photographed and videoed the Well's underwater features for park and public use. For the sampling, the YSI sonde made multiple trips through the false bottom to collect data for third-party analysis. All of the raw data from these samples was transferred to park staff for curation and long-term study. For documentation and interpretive use, SRC staff photographer Brett Seymour collected hours of video footage. An ROV operated by Conlin collected additional video. In some instances, Seymour manually guided the ROV while underwater, to position it before attempting to send the unit through the false bottom.

In conclusion, all the work encompassed in four days of intensive field work has produced, for the first time, a complete map of Montezuma Well. Although chemical analysis of the fluidized sand beneath the false bottom was inconclusive, the YSI and bulk sampling yielded a multitude of scientific information for park managers to examine and use. Former SRC Chief Dan Lenihan noted at the conclusion of his report that "the sand pools and false bottom have no known equivalents" – that is, no precedent for comparison of the data collected. The Well and its water source figure prominently as a mystery in the spiritual beliefs of the Yavapai people and even as Montezuma Well has now yielded one secret to the Submerged Resources Center, the riddle of its unprecedented spring source remains unsolved and awaits future investigation. ◘

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2006 Assessment of Physical Characteristics of Montezuma Well: A Water-Filled Sinkhole at Montezuma Castle National Monument. National Park Service Submerged Resources Center Trip Report, on File with SRC, Intermountain Regional Office, Denver, CO.

*Both publications are on file with the Submerged Resources Center and available upon request.

—CULTURAL RESOURCES—

When a SKILSAW® Just Can't Cut It: Preserving Heavy-Timber Structures in the Parks

By Randall Skeirik, Historical Architect, Vanishing Treasures Program
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The National Park Service's Vanishing Treasures Initiative (VT) was established in 1998 to facilitate the preservation of cultural resources that are in a state of ruin in national parks throughout the arid West. These resources range from pueblos and cliff dwellings to Spanish mission churches, Indian War-era forts, mining and transportation sites, and ranches and other vernacular structures. As a result of its initial successes, Vanishing Treasures was converted from a 10-year initiative to a permanent program in 2006.

While VT is often associated with earthen materials such as adobe and mud mortars, we treat such a broad range of buildings and structures that almost any type of material may be encountered. Despite this diversity of materials, one characteristic common to most VT resources is that they were built with traditional materials and construction methods, which require skills and knowledge that are rapidly being lost. From the start, one of the goals of the VT program has been to preserve and perpetuate the knowledge of these traditional materials and methods and the skills needed to use them.

Given the program's emphasis on parks and resources in the arid West, it is true that a primary focus has been on the adobe and earthen mortars typically associated with Native American and Spanish Colonial architecture. However, once into the era of Anglo-European settlement, many structures were built not just of wood, but from heavy timbers. These can include structures such as mining head frames, railroad trestles, and tramways related to mining and lumbering.

The preservation of heavy timber structures – those built of wood with large cross sections up to 12 inches wide and 18 inches deep – requires special tools and techniques that are often beyond the capability of carpenters today. VT staffers, working in cooperation with the University of Vermont School of Engineering (UVM), have recently helped to preserve heavy timber structures in three western parks. Through agreements with the Cooperative Ecosystem Studies Unit (CESU) network, VT has facilitated preservation work on the Keane Wonder Mine Tramway in Death Valley National Park in California, the Cable Mountain Draw Works in Zion National Park in Utah, and two railroad trestles at Golden Spike National Historic Site, also in Utah. These projects have helped to pull these resources back from the brink of collapse.

All of these cooperative projects have taken advantage of the special relationship between principal investigator Doug Porter and some of Vermont's best timber framers – the same guys who preserve New England's famous covered bridges. The projects have included field schools that, while preserving significant historic resources, have also allowed students, volunteers, and NPS personnel to learn, side-by-side with these skilled craftsmen, the use of traditional tools and techniques for working and joining heavy timbers.

At the same time that these projects are helping to perpetuate traditional knowledge, they often incorporate modern tools, materials, techniques, and testing processes as well. Evaluation of the heavy timber structures in these parks included the services of a wood scientist who used modern tools such as moisture meters and resistance drills to help determine the condition of wood members without damaging them.

Modern preservation treatments that help slow the deterioration of the wood may include the application of borates. In wood preservation, borates – in the form of borate salts – are used in liquid, solid, or gel forms to kill fungi and wood-eating insects while having little toxicity to plants, animals and humans. This low-impact treatment effectively addresses the two greatest causes of wood deterioration.

Another treatment recently developed in a separate cooperative agreement with UVM may have wide application for wood structures in the national parks. This treatment is designed to address the issue of ultraviolet (UV) degradation of wood. Although UV deterioration is typically a slow process, it is greatly accelerated in desert climates where the sun is very intense. UV rays actually break down lignin, a chemical compound in wood that acts as the "glue" that holds wood fibers together. This can be a significant cause of deterioration over time. (Figures 1 and 2)

Wood that has an opaque finish, such as a coat of paint, is protected from UV rays. Wood

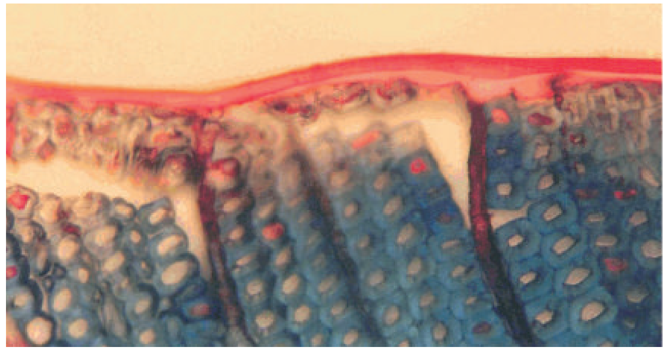


Figure 1: Even with a clear coating, UV deterioration of the coating and the substrate can occur simultaneously. Here the wood's lignin is degrading beneath the varnish coating (orange layer at top) and the wood is disgregating.
Photo Credit: University of Vermont

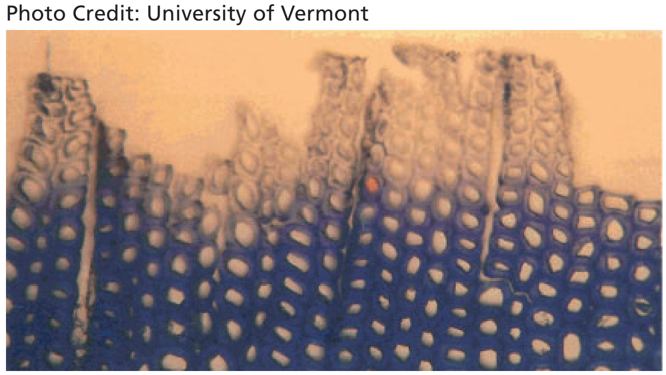


Figure 2: Deteriorated wood cells beneath the varnish have detached and the varnish coating is lost along with many of the deteriorated cells. Without protection, this cycle will be repeated, resulting in continued surface deterioration.
Photo Credit: University of Vermont

with a transparent finish or no finish at all (which describes the condition of many backcountry cultural resources) has no such protection. The challenge in developing a treatment to protect unfinished wood was to find an application that would not change the wood's appearance. This was achieved through a series of accelerated and real-time weathering tests of numerous proprietary and custom formulated protectants.

The UVM team explored several strategies for the clear or semitransparent finishing of wood: Treatment with consolidants to improve surface resistance to weathering, inorganic pigments (semi transparent deck stains) that absorb UV radiation, and the addition of UV stabilizers to clear coatings. UV stabilizers can include absorbers that convert light energy to caloric energy or heat, and hindered amine light stabilizers (HALS) that trap radicals formed by photo degradation.

The formulation that performed the best incorporated the consolidant Butvar® B-98 and BASF Tinuvin® 5151. B-98 is a polyvinyl butyral, used primarily to conserve objects, that is appreciated for its mechanical properties, depth of penetration, light and heat stability, and reversibility and re-treatability. Tinuvin 5151 is a blend of two types of light stabilizers: BTZ ultraviolet light absorbers [UVA] and a HALS. BZT filters harmful UV light while the HALS traps free radicals once they are formed. In combination, these two light stabilizers work together to prevent the breakdown of the lignin matrix of the wood, preventing increased friability and the loss of surface coherence that lead to the erosion of the wood surface.

The projects

Keane Wonder Mine, Death Valley National Park (DEVA): This gold mine was established in the earliest years of the 20th century and proved to be one of the most profitable gold mines in Death Valley. A tramway (Figure 3) was built to move the ore from the mine nearly a mile down into the valley for processing. Today, the tramway is almost entirely intact, with both the upper and lower terminals, a cross-over, and 11 of the original 12 towers still standing. Incredibly, two miles of stationary steel cable on which the ore buckets rolled is still in place, placing a huge load on the 100-year-old wooden towers. Abandoned since the 1940s, the tramway had received

Figure 3: The Keane Wonder Mine tramway, with lower terminal and the first six of its 11 remaining towers. Photo Credit: Randall Skeirik

virtually no maintenance other than emergency stabilization treatments in the 1990s.

Beginning in 2009, DEVA and UVM began to assess and then stabilize the tramway towers and terminals. Initial work focused on the lower terminal, which was easily accessible by vehicle. Later, the work moved up the mountain to the towers and the upper terminal, which required a helicopter to transport supplies and materials to the job sites.

At the lower terminal, the ends of many of the supporting posts had been buried under sediment that had washed down the mountain. Despite the arid climate, ground moisture had led to deterioration of the buried wood. In keeping with a basic tenet of historic preservation – the retention of as much original material as

Figure 4: In keeping with preservation philosophy, only the deteriorated portions of framing members were removed. The bottom end of this post has been replaced with new, matching material. This splice joint was laid out and cut by the VT historical architect under the supervision of a timber framing expert. Photo Credit: Randall Skeirik

possible – the team removed only the deteriorated ends of these posts so that new wood could be spliced to the still-sound upper sections (Figure 4). In many cases, the original timber posts were cut to odd sizes, so it was necessary to trim the new timbers to match the originals. Because even a 12-inch circular SkilSaw is too small to trim such large timbers, the team used traditional tools such as mallets, chisels, and slicks to dress the timbers down to the correct size. (Figure 5)

At the conclusion of the two projects, both the upper and lower terminals (Figure 6) and several of the towers (Figure 7)

Figure 5: Death Valley National Park employee Jeremy Stoltzfus uses mallet and chisel to properly size a replacement timber. Timber framer Mike Controneo works on a scarf joint in the background.
Photo Credit: Randall Skeirik

Figure 6: New diagonal bracing, with repairs to posts, ensures that the lower terminal will remain standing.
Photo Credit: Randall Skeirik

Figure 7: Tower 7 (at right), on the edge of the canyon, was about to collapse. Assessment of each member led to replacement of only those members or portions of members too deteriorated to be repaired. One of the last remaining ore buckets hangs between Towers 8 and 9. Photo Credit: Randall Skeirik

were stabilized. Although more work remains to be done on this engineering marvel, the most urgent repairs have been made, assuring that the tramway will remain an attraction to park visitors for years to come.

Cable Mountain Draw Works, Zion National Park: This unassuming structure holds great significance to local residents around Zion National Park. Mormon pioneers first settled Zion Canyon in 1862, but they had no good local source for timber. Although good timber was available on the nearby mesa tops, it took one to two weeks to haul it down into the canyon.

A diary entry from 1863 recounts that when Mormon leader Brigham Young visited the canyon that year he predicted that timber would someday come down from the mesa tops "like a hawk flies."

More than 35 years later, a young local man set out to fulfill what he believed to be prophecy by building a cable system that would carry lumber from the mesa to the canyon bottom in a matter of minutes. In 1901, after several sometimes dramatic failures, he finally succeeded, and to this day the remains of the Cable Draw Works are seen by many Mormons as the physical embodiment of prophecy fulfilled.

For two-and-a-half decades, several different incarnations of the Cable Mountain Draw Works (Figure 8) brought the

Figure 8: Undated view of the last known version of the Cable Mountain Draw Works, the remains of which Zion National Park stabilized in 2010. Photo Credit: Unknown

plentiful lumber of the mesas to the growing town of Springdale down in the canyon. But by 1925, the supply of timber had been exhausted and in 1930 the National Park Service removed the cable and later demolished the lower terminal. Today, all that remains is the upper terminal, perched on the canyon's edge.

The park conducted periodic maintenance on this structure, including the installation of diagonal tension members and the application of water repellent treatments. However, by the turn of the 21st century the structure was in such poor shape that it had been tied back with steel cables to prevent it from tumbling over the cliff edge should it collapse. (Figure 9) One of its four legs had rotted off well above the ground, causing the whole structure to list to one side. Many of the beams were so rotten that they could barely support their own weight and were sagging badly.

In 2010, the park began a project to stabilize the Draw Works. As with the Keane Wonder Mine Tramway, a wood scientist evaluated the condition of each member so that only the sections that were deteriorated beyond repair were replaced. With the evaluation complete and replacement timbers on site, the structure was carefully disassembled for repair. (Figure 10) The UVM team used a combination of modern and traditional tools to fabricate replacement pieces and fit the splices into place. (Figure 11)

Figure 9: Upper terminal of the Cable Mountain Draw Works prior to preservation. Note the deteriorated corner post, which causes the structure's forward lean, and cable looped around the structure to prevent it from tumbling over the cliff should it collapse. Photo Credit: Randall Skeirik

Figure 10: Workers use a traditional gin pole with a block-and-tackle to lower the front bent of the Draw Works. Workers, when in proximity to the cliff edge, wore harnesses and were securely belayed. Photo Credit: University of Vermont

Figure 11: A volunteer learns how to use an adz to shape a timber.
Photo Credit: University of Vermont

Figure 12: The rehabilitated Draw Works. Only members deteriorated beyond repair were replaced. Where possible, splices joined sound historic material to new replacement wood to retain as much original material as possible. Photo Credit: Randall Skeirik

Today, the upper terminal of the Cable Mountain Draw Works is no longer in danger of collapsing over the cliff edge. It looks much like it did when it sent its last load down to the canyon in 1925 (Figures 8 and 12). This important historic resource – to some the fulfillment of prophecy and to all the proof of early southern Utah settlers' determination to build a new life – has been returned to "good" condition and will require only routine maintenance.

Wooden railroad trestles, Golden Spike National Historic Site:

This park was established to commemorate the place where, in 1869, the Union Pacific Railroad working from the east and the Central Pacific Railroad working from the west met to complete America's first transcontinental railroad.

Figure 13: Trestle One, with severely deteriorated east-bent posts, failing head wall and stringers. The stone gabion baskets were installed by the National Park Service in an earlier stabilization effort.
Photo Credit: Randall Skeirik

Figure 14: Trestle Two, showing creosote-treated posts and beams. The stringers that run the length of the trestle were not creosote treated and show significant deterioration that will require repair. Photo Credit: Randall Skeirik

Although the railroad grades still exist, the rail line through the park was relegated to a secondary line in 1903 and, in 1943, the track was removed and scrapped in support of the war effort during World War II.

Along the entire alignment through the park, only two wooden trestles remain. Trestle One (Figure 13), which dates from the 1890s, was built with traditional trestle construction using square timbers. Trestle Two, dating from the 1920s, has round timbers for its posts and was preserved with creosote, a treatment that was not available when Trestle One was built. As a result, Trestle Two remains in relatively good condition except for the stringers that supported the railroad ties.

Trestle One, on the other hand, suffered substantial deterioration; by 2010, it was on the verge of collapse. (Figure 13)

As with the other projects described here, trestle rehabilitation began with an assessment by a wood scientist and a determination of which members would need repair or replacement. In the case of Trestle One, many of the timbers were so severely deteriorated that they had to be entirely replaced. (Figures 13 and 15) An analysis of each member suggested that this trestle had been repaired a number of times before. Although most of the remaining timbers were Douglas fir, two of the posts were cedar and one was redwood, suggesting that they were replacements. In addition, the unusual configuration of the trestle's west bent (a framework of several structural members that defines the cross-section of a timber frame building or supports a trestle), which had only four posts (the east bent had five), suggested it may have been rebuilt. Further, the bottom end of all four posts in the west bent had been cut off well above grade and was supported on a horizontal timber that was itself supported on four short posts. This indicated a second, later modification of this bent, probably because the replacement posts had rotted.

Just as historic preservation tenets stress that original fabric should be retained to the greatest extent possible, they also require that existing conditions be maintained unless a structure is returned to an earlier documented condition. Because the project team did not know for a fact that the west bent had been modified, everything was replaced to match the existing conditions, even retaining its structurally flawed design.

In the end, sections of the stringers in Trestle Two were replaced and Trestle One got a thorough makeover (Figure 16), returning both to "good" condition. With the addition of new ties, decking, and railings, these trestles will be ready to be incorporated into a new hiking/biking trail anticipated for the rail alignment in this section of the park.

These three projects exemplify how the Vanishing Treasures Program, working with partners through the CESU program, is helping to preserve historic resources in the parks. The program strives to perpetuate traditional knowledge and skills while also embracing modern, state-of-the-art materials and processes that, in combination, help achieve the highest level of cultural resource stewardship.

Figure 15: Stockpiled timbers at the site of Trestle One. The crane is about to lift a replacement post into place. Photo Credit: Randall Skeirik

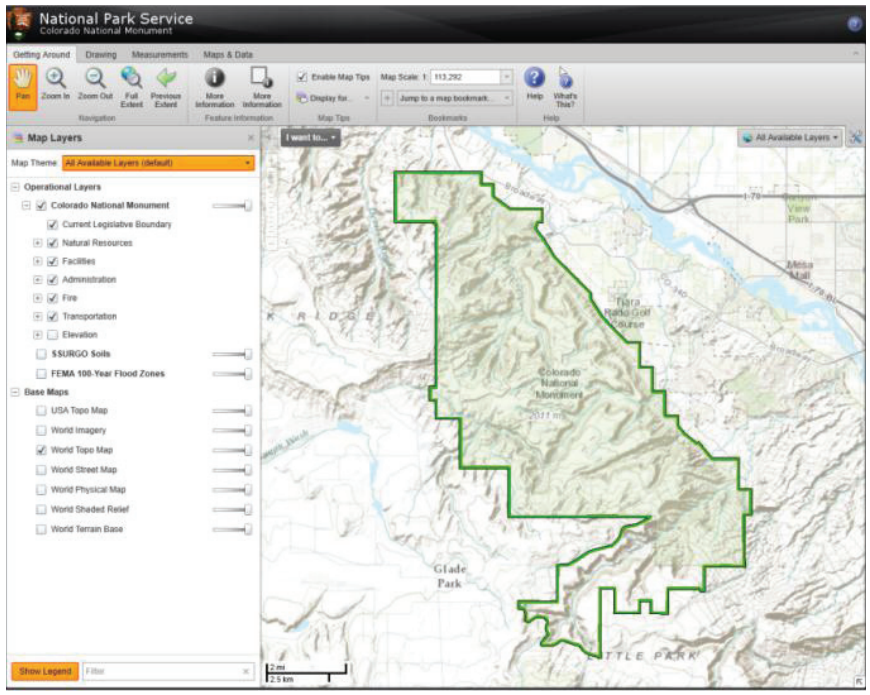
Figure 16: Crew members, including students, park staff, and timber framers, pose with principal investigator Doug Porter (third from right, back row) on the rehabilitated trestle. Note the scarf joint joining new and historic material on the front stringer. Photo Credit: Holly Strachan

—GEOGRAPHIC RESOURCES—

Using Web-Based Interactive Maps to Support Planning

By Darcee Killpack, Chief, intermountain Region Geographic Resources Division
darcee_kilpack@nps.gov

The Intermountain Region Geographic Resources Division is working to increase access to geospatial data to support park planning and management, as most parks do not have full-time Geographic Information Systems (GIS) staff. Getting access to geospatial data can be difficult because GIS requires specialized software and skills to manage and manipulate the data. Fortunately, web-based technology is advancing and most computer users are now familiar with online mapping sites such as Google Maps and MapQuest.



The IMR GIS division is looking to tap into that familiarity by developing tools to help staffers at all levels in the parks increase their access to and use of GIS data, putting this important information into the hands of superintendents, planners, resource managers and others. This work will not replace the need for trained GIS staff, but it will allow existing GIS staff to be more efficient and concentrate on data updates, collection, analysis, and support of a broader base of GIS users in the parks.

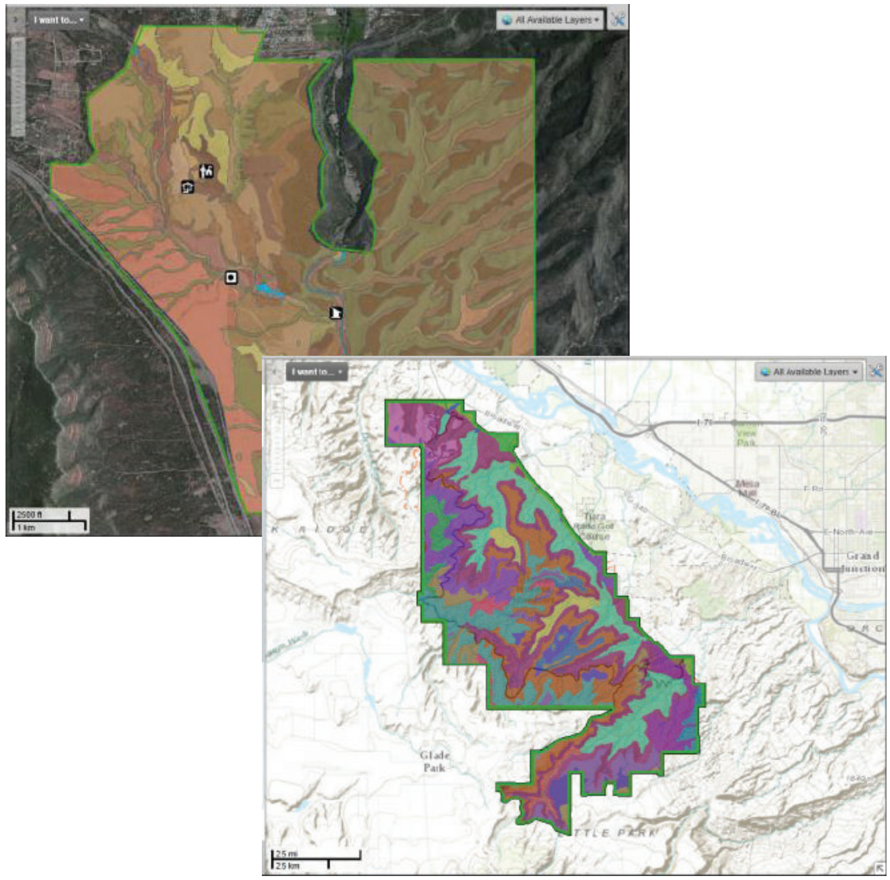
How are we doing this?
IMR GIS is creating custom, web-based mapping viewers for parks. These are simple Internet browser-based maps that include tools for using park data and features. The viewers also allow users to control what features they see and don't see.

A mapping viewer does not require special software, as it runs in all modern Internet browsers. It requires only a simple browser plug-in that can be easily downloaded from the Internet for any computer.

What does the viewer contain?

Available in the viewer are geospatial data, such as:

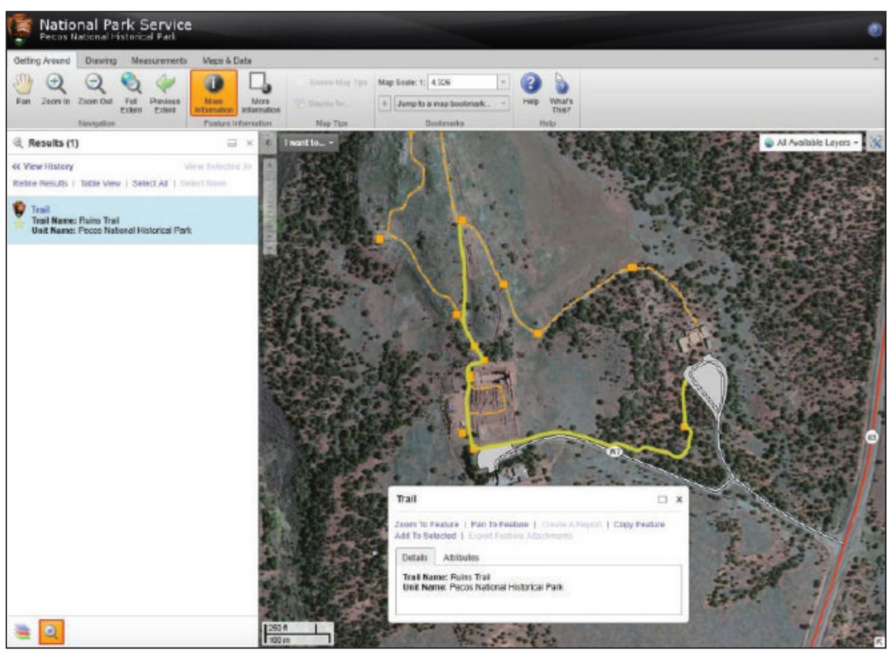
- Geographic boundaries: legislative boundaries, previous boundary designations, ownership data, management areas, wilderness lands
- Infrastructure: facilities, buildings, utilities
- Transportation: roads and parking
- Visitor Use: campsites and trails
- Natural Resources: soils, geology, rivers, lakes, and vegetation
- Base maps: aerial photography, topographic maps, and street maps



What can you do in the viewer?

Users can perform many common tasks in the viewer, including:

- Zooming in and out to see more or less detail about an area
- Selection of specific features to learn more information about them
- Measurement of distances and areas
- Drawing of graphics and text on maps

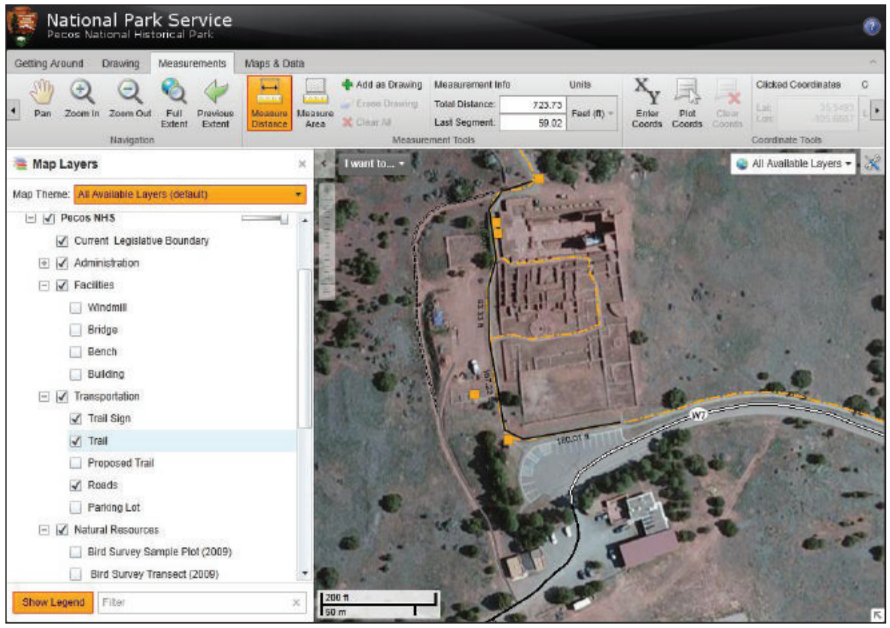


This graphic shows how a user can click on a trail and learn more information about it. Other information such as condition, type, and use of the trail or a photo from the trail can be included in pop-up information windows.

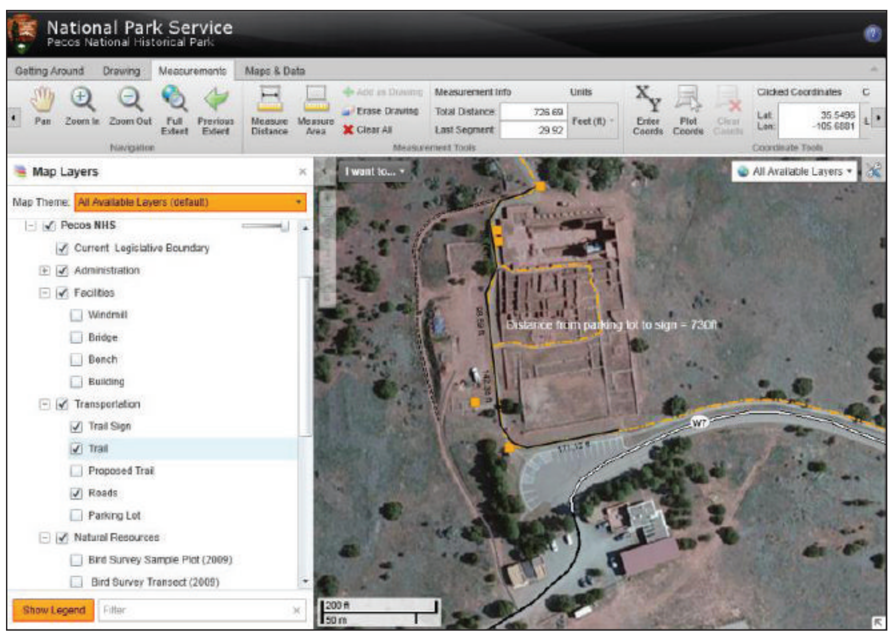
- Printing of custom maps (as PDFs, JPEGs, TIF files and the like) based on the area and features in the view
- Saving of new maps, including notes and graphics, and sending to co-workers for review
- Determination of location coordinates or dropping coordinates on a map
- Addition of other Internet-compatible data

How are web-based maps being used?

The National Park Service has undertaken a national initiative to integrate geographic information into the park planning process. This initiative is creating a comprehensive, GIS-based map collection called a Park Atlas. Based on both paper and online web-based maps, a Park Atlas will support present and future planning activities and give parks, regions, and programs access to baseline GIS data to support day-to-day operations. A Park Atlas helps establish a base for future planning projects using accessible GIS data and tools. Parks also use the viewers to help with compliance for new and current maintenance requests, operational pictures of park resources, and cross-program planning.



Graphic showing how a user can measure distances in the map. Viewer tools also allow users to measure area and change units of measure.



Graphic showng how a user can mark up a map by adding shapes and text.

Park Atlas Gallery:
http://insideparkatlas.nps.gov

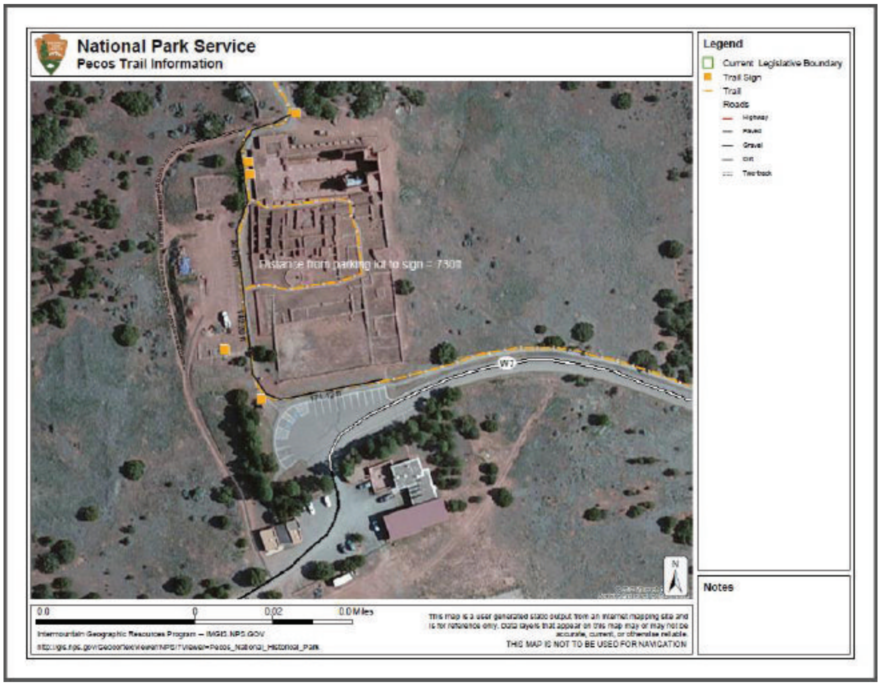
IMR GIS Internal Site:
http://gis.nps.gov

Who has access?

At present, all Park Atlases are accessible internally only by NPS staff. However, atlases can be made available to cooperators and the public to increase their engagement with parks. Limited datasets or simpler viewers also can be created to tailor the information and tools to general public needs.

Park Atlas and other web-based mapping viewers are tools to increase awareness and access to critical geospatial data for all park staff. These viewers are easy to use, don't require specialized skills or training, and help put geospatial data in the hands of park staff for better planning and decisions.

This effort, combined with IMR GIS's previous efforts to invest in these tools, has exposed the viewers to more parks and increased access to GIS data for all park and program staff.



The graphic shows an example map, in PDF format, created from the viewer. This map can then be emailed, printed, or added to another document/report.

—LANDSCAPE CONSERVATION— AND CLIMATE CHANGE

Developing Partnerships and Tools to Promote Climate Change Adaptation

By Tom Olliff,[1] Patrick Gonzalez[2] and Pam Benjamin[3]

[1]Great Northern LCC Co-Coordinator, NPS IMR Chief, Landscape Conservation and Climate Change;
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[3]IMR Climate Change and LCC Coordinator

Introduction

Field research has detected widespread historical changes in ecosystems that analyses have attributed to anthropogenic climate change (IPCC 2007b, Rosenzweig et al. 2008). Changes found in U.S. national parks and attributed to climate change include shifts of vegetation biomes in Noatak National Preserve (Suarez et al. 1999), shifts of small mammal ranges in Yosemite National Park (Moritz et al. 2008), increases in tree mortality in Rocky Mountain National Park and other western parks (van Mantgem et al. 2009), and reduction of snowpack at Glacier National Park and other western parks (Pederson et al. 2011). If carbon emmisions continue, ecosystems may be exposed to novel climate regimes (Williams et al. 2007, Williams and Jackson 2007), biomes may be vulnerable to extensive latitudinal and elevation shifts (Gonzalez et al. 2010), individual species such as Joshua tree (Yucca brevifolia; Cole et al. 2011) and American pika (Ochotona princeps; Erb et al. 2011) may be vulnerable to range shifts, and other resources may be vulnerable to climate change.

The National Park Service (NPS) response to climate change operates within several federal directives introduced since 2007 to reduce emissions of greenhouse gases (GHGs), achieve sustainability, and implement science and planning tools for adaptation. These directives invoke two fundamental tactics that address climate change: 1) mitigation (activities that either reduce GHG emissions or enhance their removal from the atmosphere) and 2) adaptation (activities that help people and natural systems cope better with climate change effects by moderating harm or exploiting beneficial opportunities). The 2010 NPS Climate Change Response Strategy (CCRS), coupled with two implementation plans—the Climate Change Action Plan (CCAP) and the Green Parks Plan (GPP)—put the federal directives for climate change adaptation and mitigation into practice for the NPS.

The Landscape Conservation and Climate Change program (LC&CC) is a new division in the NPS Intermountain Region's (IMR) Resources Stewardship and Science directorate. It works with partners such as the NPS Climate Change Response Program, the IMR Green Team, Department of the Interior (DOI) Landscape Conservation Cooperatives and Climate Science Centers, and universities to connect parks to larger landscapes and understand and promote climate change adaptation. In order to enhance park capacity for undertaking strategic activities for climate change adaptation, park managers need tools that can support science-based, adaptive park management. These tools include: scenario planning; resource vulnerability assessments; historical climate change data and future projections; ecological and cultural resource response models; frameworks for developing adaptation actions; and risk assessments

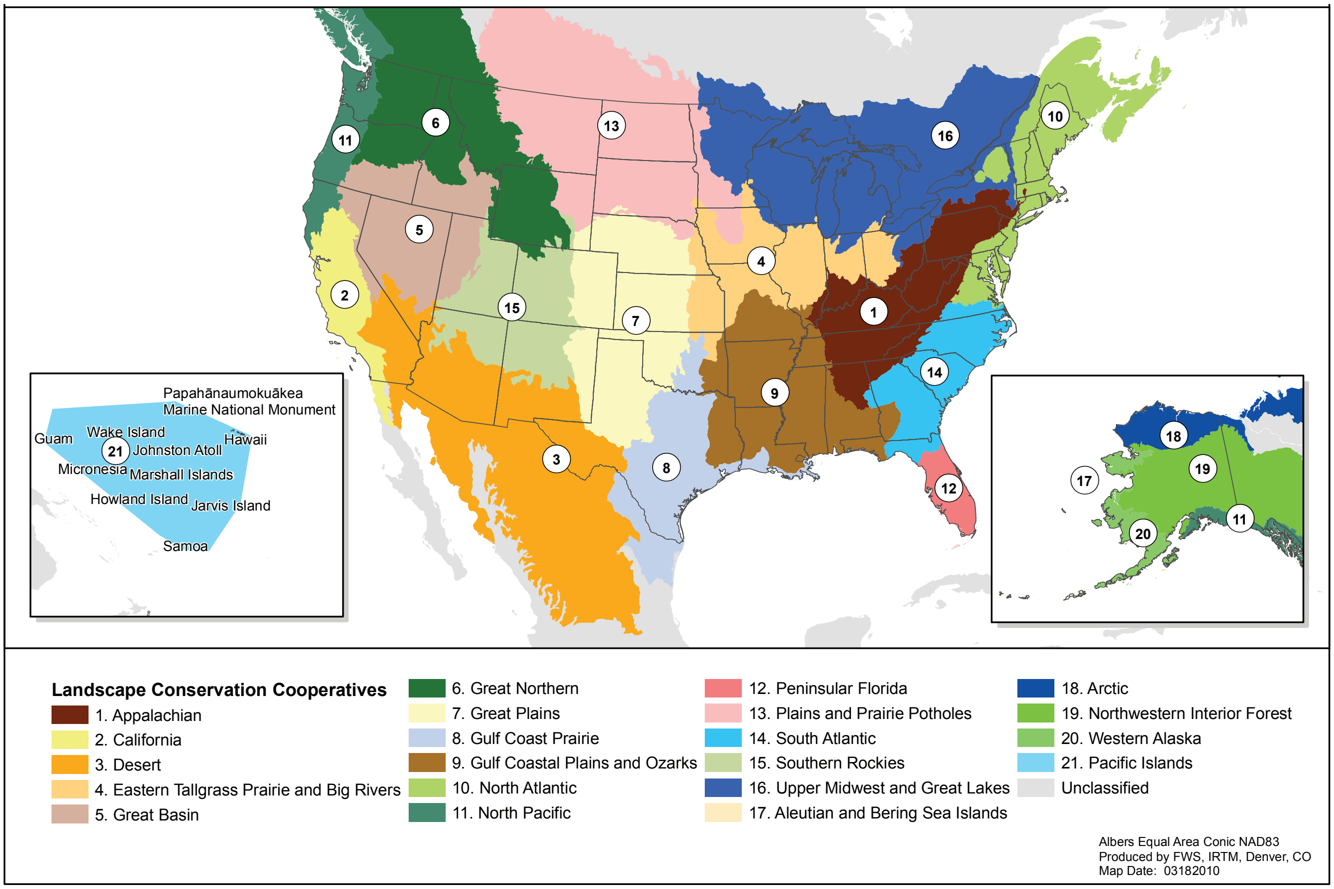

Figure 1: Network of 22 Landscape Conservation Cooperatives. The Great Northern, Southern Rockies, Gulf Coast Prairie, and Desert serve most IMR Parks (from Austen 2011).

for understanding the consequences of acting or not taking action (Gonzalez 2011). Working with partners to develop these tools, the LC&CC program connects the tools to parks.

Principal Partners In Climate Change Adaptation

DOI landscape and climate change partners

Established in 2009 by Interior Secretary Ken Salazar, Landscape Conservation Cooperatives (LCCs) and Climate Science Centers (CSCs) are intended to provide the latest science to land managers and conservation partners and work with federal, state, tribal, and local governments, and private landowners and NGOs to "develop landscape-level strategies for understanding and responding to climate change impacts" and to help managers sustain the continent's natural and cultural resources (Secretarial Order 3289). While each LCC is led by a self-directed steering committee, all of them have three features in common: 1) they use applied conservation science in with partners within a geographically defined area; 2) they function as a fundamental unit of planning and adaptive science that will help and guide decisions unit level; and 3) they provide a national (and international) network of land, water, wildlife and cultural resource managers, and interested public and private organizations (Austen 2011). CSCs deliver basic climate change impact science

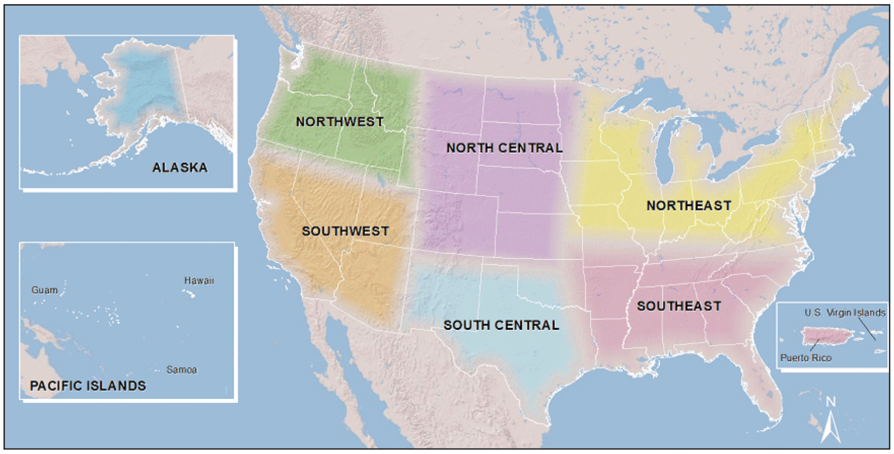

Figure 2: Map of the 8 Climate Science Centers. The North Central, South Central and Southwest serve most IMR parks (from Beard 2011).

to field managers within their respective regions, including physical and biological research, ecological forecasting, and multi-scale modeling. CSCs prioritize delivery of fundamental science, data and decision support to meet the needs of the LCCs. This includes providing them climate change impact information on natural and cultural resources and developing adaptive management and other decision support tools for managers. These regional CSCs are based at host institutions with substantial expertise and partnerships in climate change science. CSCs include a cadre of U.S. Geological Survey and University Consortium (UC) staff. One member of the UC will serve as the host for each of the respective CSCs (Beard et al. 2011). By the end of 2013, the full suite of 22 LCCs (Figure 1) and 8 CSCs (Figure 2) will be operational.

Most IMR parks are included within four LCCs: Great Northern, Southern Rockies, Gulf Coast Prairie, and Desert. The Great Northern LCC (seven IMR parks), co-led by the U.S. Fish and Wildlife Service (FWS) and the NPS, includes large parts of Idaho, Montana, Oregon, Washington, Wyoming, and the Canadian provinces of British Columbia and Alberta—an area of approximately 260 million acres. The Southern Rockies LCC (34 IMR parks), co-led by the FWS and the Bureau of Reclamation (Reclamation), encompasses large portions of Utah, Colorado, Arizona, and New Mexico. The Gulf Coast Prairie LCC(five IMR parks), led by the FWS, includes portions of Texas, Oklahoma, Louisiana, Mississippi, and Kansas. Reclamation and the FWS co-lead the Desert LCC (21 IMR parks), which encompasses portions of five U.S. states, parts of at least 10 states in Northern Mexico and covers the geographical boundaries of the Chihuahuan, Sonoran and Mojave deserts.

While LCCs work within defined geographic boundaries, the geography of CSCs is broader and more “fuzzy,” tending to work within the context of cooperating universities. All IMR parks are covered by the geographical boundaries of either the Northwest, North Central, Southwest, and South Central CSC’s (see Figure 2.). The Northwest CSC is hosted by three major universities: Oregon State University, University of Washington, and University of Idaho and works with a wide range of additional partner institutions. The North Central CSC, is hosted at Colorado State University and includes eight other universities: the University of Colorado Boulder, Colorado School of Mines, University of Nebraska-Lincoln, University of Wyoming, Montana State University, University of Montana, Kansas State University, and Iowa State University. The South Central CSC is hosted by the University of Oklahoma and includes Texas Tech University, Oklahoma State University, the Chickasaw Nation, the Choctaw Nation of Oklahoma, Louisiana State University, and the National Oceanic and Atmospheric Administration’s (NOAA)

Geophysical Fluid Dynamics Laboratory. The Southwest CSC is hosted by the Southwest Climate Alliance, a consortium of six institutions: University of Arizona; University of California, Davis; University of California, Los Angeles; Desert Research Institute, Reno; University of Colorado Boulder; and the Scripps Institution of Oceanography at the University of California, San Diego. As the basic science and tools are developed, LCCs, CSCs, and the IMR LC&CC program staff reach out increasingly to parks to make them available and usable.

The NPS Climate Change Response Program

In 2007, the director of the National Park Service established the Climate Change Response Program (CCRP) under the Natural Resource Stewardship & Science (NRSS) Directorate to work with parks, regions, other directorates, programs, and partners to develop an interdisciplinary approach to the challenges of climate change. To allow for service-wide involvement in exploring the needs and issues of parks, several working groups were formed beginning in 2008. A Climate Change Steering Committee, created in early 2009 and including park, regional, and Washington office representatives, worked to foster communication and guide the development of a service-wide strategy. The NPS secured base funding for the CCRP beginning in FY 2010, and program strategy was launched in September 2010. The CCRP is a cross-disciplinary program to provide guidance, training, technical expertise, project funding, and educational products that support action to preserve the natural and cultural resources and values of the National Park Service.

Featured Project: Historical and Projected Climate Change Trends for All Parks

NPS climate change scientist Dr. Patrick Gonzalez of the Climate Change Response Program is collaborating with the University of Wisconsin Center for Climatic Research to provide spatial data on historical and projected climate for all national parks at finer spatial scales than currently available. This project will: 1) Spatially analyze historical and projected climate trends for the United States; 2) Characterize uncertainties of historical climate data and projections; 3) Produce a consistent set of climate information at an appropriate spatial scale that every national park can use for vulnerability analyses, resource management planning, and development of climate change adaptation measures. It will be a valuable tool in developing scenarios for climate change adaptation.

Spatial resolution — Spatial resolution is the key parameter for any research using spatial climate data in raster or grid format. Interpolation of point meteorological station data to grids can produce spatial data of historical climate. For historical spatial climate data, the density of meteorological stations, spatial resolution of the digital elevation model used in the interpolation, limitations of the interpolation method, and the spatial variation of the climate variable of interest determine the appropriate spatial resolution. The density of the meteorological stations is generally the most crucial factor, particularly in mountainous regions where topographic complexity increases meteorological variability. In these areas, the observational data strongly constrains the reliable spatial resolution of the gridded data.

Because general circulation models produce spatial output at coarse spatial resolutions, downscaling to finer resolutions is needed to produce data useful to resource managers. The spatial resolution of historical climate grids determines the possible spatial resolution of downscaled future climate projections. Because temperature changes do not vary much over large spatial

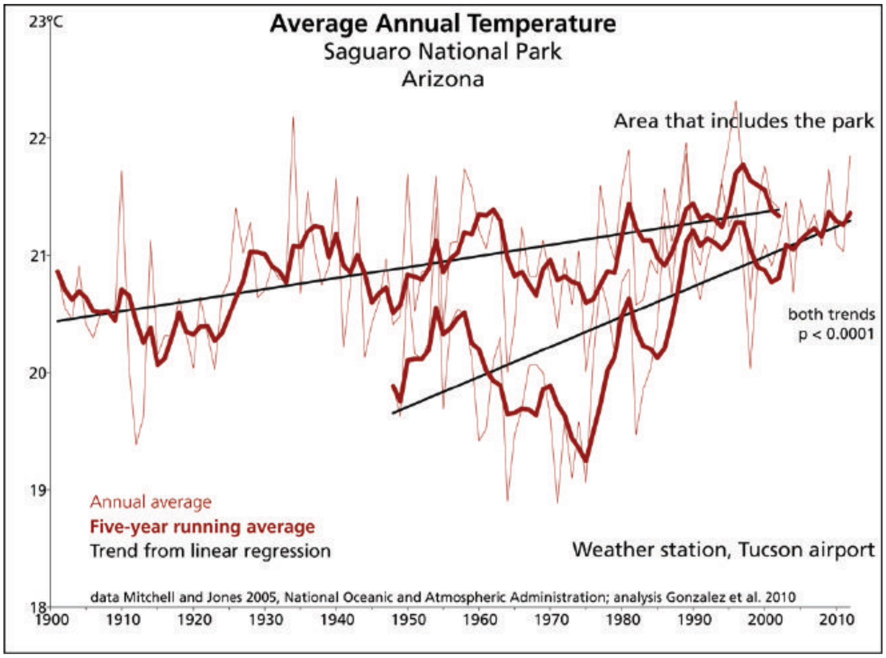

Figure 3. Historical temperature for the Tucson Airport weather station and for the 50 km x 50 km pixel that includes Saguaro National Park, showing statistically significant warming.

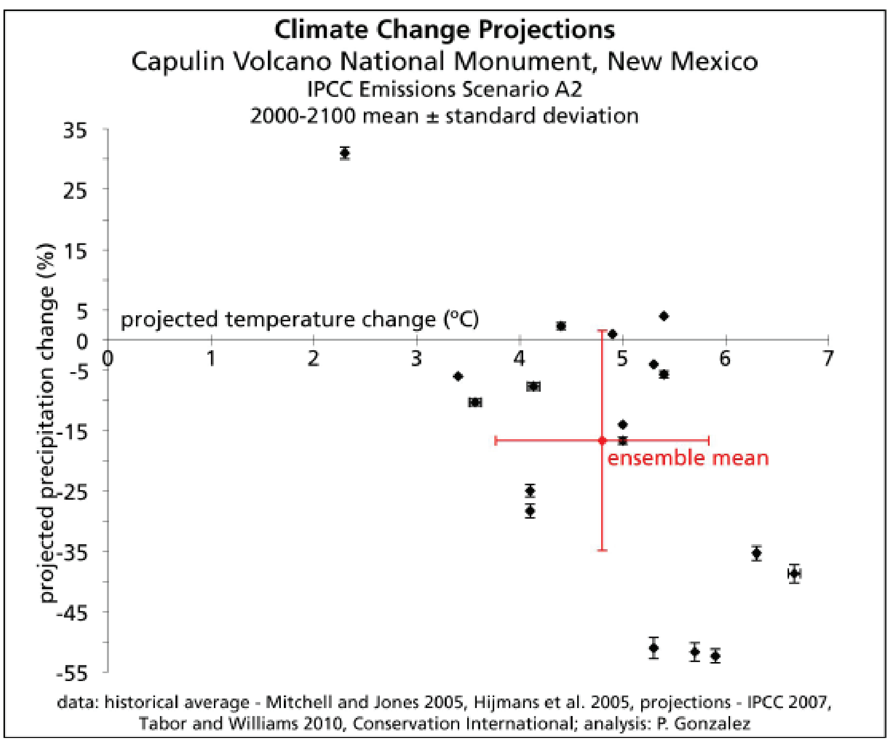

Figure 4. Projected temperature and precipitation in the 4 km x 4 km pixels that include Capulin Volcano National Monument, showing the cloud of potential futures if we do not reduce greenhouse gas emissions from motor vehicles, power plants, and other human sources (IPCC Emissions Scenario A2).

scales, reliable interpolation to a fine grid is possible using digital elevation and lapse rate models. Precipitation, on the other hand, can vary widely, especially in the mountainous terrain found in many U.S. national parks. Downscaling coarse climate data to spatial resolutions of 4 km or less generates a risk of inferring more spatial information than exists in reality. Uncertainty is higher for downscaled precipitation than for downscaled temperature data of the same spatial resolution. Because of limitations on the scientific validity of downscaled climate data, resource managers may need to accept data that is coarser than they might want.

Historical climate data — Spatial data on historical and projected climate at the appropriate spatial and temporal scales provide the fundamental information needed for resource management under climate change (Tabor and Williams 2010). The University of East Anglia Climate Research Unit (CRU) has derived historical spatial climate data at spatial resolutions of ~50 km; (Mitchell and Jones 2005) and ~16 km; (New et al. 2002) from point measurements of weather stations in the Global Historical Climatology Network (Peterson and Vose 1997). The NPS project is using historical climate data downscaled to

800 m spatial resolution for the 48 contiguous U.S. states (Daly et al. 2008), 2 km spatial resolution for Alaska, and 16 km for Hawai'i and other U.S. islands.

Projected climate data—The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007a). The NPS project is using the new emissions scenarios that the IPCC will publish toward the end of 2013 and all available general circulation models of the atmosphere. It will produce temperature projections for the 48 contiguous U.S. states at 800 m spatial resolution for temperature and 8 km spatial resolution for precipitation and projected climate at 2 km spatial resolution for Alaska and 16 km for Hawai'i and other U.S. islands.

Current and planned results—Reports of climate change trends and ecological impacts at coarse spatial resolution are already available for numerous parks on ShareNRSS, the NPS SharePoint site for natural resources, at http://sharenrss/climatechange/Planning/Climate%20Change%20Science%20for%20Parks. These reports primarily support the integration of climate change information into NPS Foundation Documents.

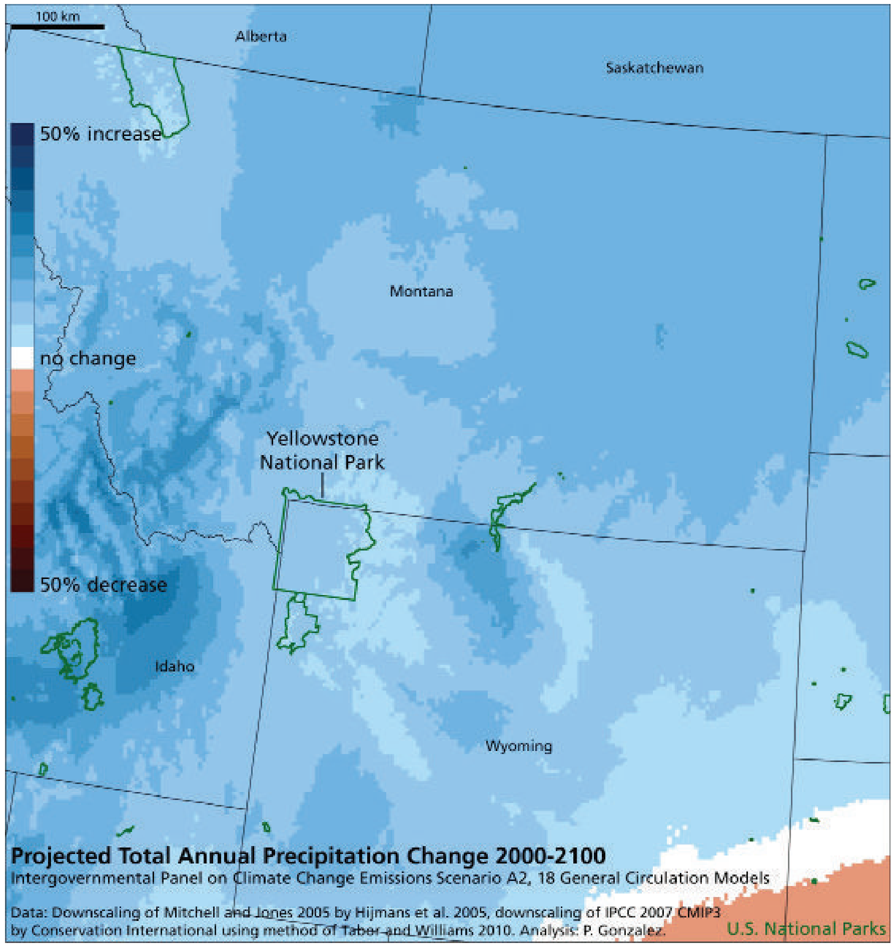

Figure 5. Projected total annual precipitation changes in the northern Rockies, comparing the average of the 2071-2100 projections of 18 general circulation models for the warm IPCC emissions scenario (A2) with the historical 1950-2000 average.

Parks with reports include Bent's Old Fort, Capulin Volcano, Rocky Mountain, Bryce Canyon, Yellowstone, and others. See Figures 3-5 for examples of the results in these reports. The data downscaled to finer spatial resolution are scheduled for completion in late 2013. Products will include Geographic Information System (GIS) spatial data files posted to NPScape (the NPS data web site), information by park (text, tables, time-series graphs, key maps), and peer-reviewed scientific publications.

Next Steps

IMR Green Team

In 2012, Regional Director John Wessels formed the IMR Green Team to coordinate and help guide the Intermountain Region toward a sustainable future using the Green Parks Plan and the Climate Change Response Strategy as foundation documents. Team members were selected in November and the first working meeting was held in January 2013. The Green Team will support regional and park staff in gaining a better understanding of sustainability and climate change. It also will facilitate meaningful conversations across disciplines and levels of authority. The team will strive to give regional staff the tools, knowledge and policy support necessary to ensure that the region is consistently moving forward to preserve the park's resources – and the world's – unimpaired for future generations.

IMR Handbook for Park-based Climate Change Adaptation Strategies

The LC & CC program staff is developing a handbook that refines strategies from the NPS-CCRS and the NPS-CCAP by outlining seven steps to help groups of parks develop climate change adaptation strategies for key resources. These strategies can be used to define both short- and long-term actions to address climate change effects. Parks that implement this process can:

- Apply scenario planning and resource vulnerability assessments and engage with partners to implement adaptation strategies
- Build effective, science-based options to inform park management
- Build a learning network of best practices and adaptation expertise within the National Park Service
- Enhance the implementation of collaborative adaptation among partner agencies and stakeholders.

The Guide is being developed in consultation with the Climate Change Subcommittee of the IMR Resources Stewardship Advisory Team, and with other key partners, such as the NPS Climate Change Response Program and the NPS Inventory and Monitoring Program. It is expected be available in 2013.

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—NATURAL RESOURCES—

Armchair Visits to Geological Underworlds: Virtual Cave Tours of El Malpais National Monument

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Introduction

Lava caves are among the main treasures of El Malpais National Monument in New Mexico, but they are not an easy resource to enjoy. When the authors recently took a group of university freshmen to one of the monument's caves, one tall 18-year-old remarked that the trail was the worst he had ever hiked. Even for the reasonably fit, walking on lava is difficult and demanding. The monument's tricky topography is only one of several factors that can discourage visitors from experiencing the beauty and other-worldliness of these caves in person. The rough terrain can prevent people with disabilities or poor conditioning from reaching the caves. The sensitive and fragile nature of some caves makes them inaccessible to visitors. The recent discovery and spread of white-nose syndrome, a pathogen fatal to bats, has led monument managers to close the caves as a precaution. Seasonal weather conditions make some monument roads impassable, further blocking access to the backcountry caves. As an alternative to in-person visitation, we have created game-like virtual tours that not only showcase these park resources, but engage visitors in exploring the caves' scientific and historical features. We aim to give visitors a realistic cave experience and to fire their imaginations about how these amazing resources formed and what life and geological features they contain today. If we have done our job well, these virtual tours also will inspire young visitors to want to learn more about the science and history of the caves.

A New Reality

Virtual tours have proven to be effective elsewhere, including in Glacier and Acadia national parks and a wide variety of other venues. Their form and effectiveness, however, can vary considerably. There are click-to-change slide shows with captions as well as click-to-move panoramas. There also are 360° panoramas that allow users to move around and zoom in and out. There is even a computer game-based virtual reality that allows users to move through the cave at their own pace: "Caver Quest," (CQ) developed by Ron Lipinski for the Snowy River passage in south-central New Mexico's Fort Stanton Cave. CQ was a first-of-its-kind virtual tour that inspired our work. With the exception of CQ, the viewer is stuck at the location where the photos were taken, at best zooming in and out some. A game-based system such as CQ is a more realistic virtual tour, allowing users to control how the cave is lit, how fast they move, where they look, and how closely they examine the cave walls.

In the four El Malpais virtual tours we are developing, we use a newer computer-game engine, the Unreal Development Kit (UDK). We also include additional data for the curious user: icons that users click on when they want more information. These lead to text or multimedia presentations on the biology, geology, archeology, and historic uses of the cave. Figure 1 shows a sample text

Why is there an oasis of brilliant green moss in the cave? Moss gardens, such as the one you see as you first enter Four Windows Cave, often occur under skylights in the caves of El Malpais National Monument. Look and you will see that there are all kinds of detritus (dead tree limbs, leaves, etc.) that have fallen in through the skylights to land in the moss garden. Moisture also enters through the skylight, and in winter when it snows you can see four shafts of snow falling on the moss garden from the four skylights. Moisture tends to be retained in the moss garden and enough sunlight enters through the skylights to fuel photosynthesis by the moss. Look closely at the moss (from edge of the moss garden please as it's very fragile and easily damaged!) and you may notice that there are spiders, mites, and insects moving around through the moss, feeding on the dead matter and other living organisms in the moss and detritus. We've even seen a frog once! The moss garden is a refuge for all kinds of life.

Figure 1: An example of additional information text available to virtual visitors who want to learn more about the biology of Four Windows Cave.

presentation for a feature of one of the El Malpais caves.

Make It So, Joe!

In our original proposal, we planned to use real estate virtual tour software—a simple but boring click-to-move set of photos of the caves. It was straightforward and would have been simple to produce and fast. Then opportunity came knocking—and we answered. Joe Darrin, an undergraduate student working on our project and a student in the Interdisciplinary Film and Digital Media Program at the University of New Mexico, took one look at our idea and declared it dead on arrival. From the perspective of someone who grew up with highly interactive, photo-realistic computer games, our proposal was boring. So we looked further and discovered Lipinski and his "Caver Quest," which he had developed after we wrote our first proposal. Lipinski's system was much closer to what Darrin recognized: our virtual tour had to be capable of holding the interest of younger, tech-savvy users, while still appealing to older visitors. Darrin recommended a different, newer game engine that would display more realistic 3-D images.

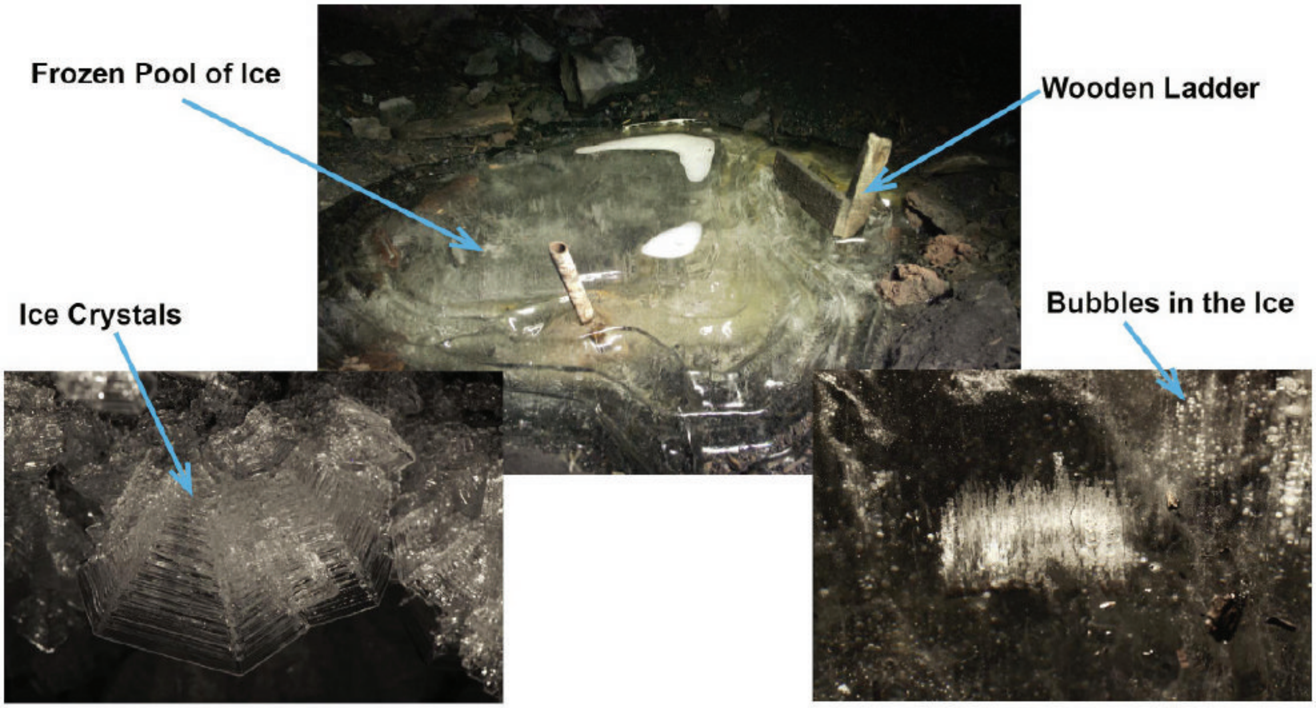
To make use of this game engine, Darrin first had to create a 3-D model of the cave. He based the model on cave maps supplied by the monument, supplemented by notes, photos and videos he took while visiting the caves. We also had to photograph every square centimeter of each cave, a process that took many days per cave, two photographers, and multiple photo assistants. Darrin digitally stitched the photos together, and then mapped the photos onto the 3-D model of the cave. The mapping proved to be a greater challenge than expected. When the photographer takes a photo, it provides only one view/aspect of the cave passage coming up, while different aspects of the same feature are revealed as the photographer moves down the passage. This poses problems in the mapping of the photos onto the 3-D model, which took time to resolve. The result was a realistic cave that the virtual visitor can explore – and a scientist (the main author of this paper) who now understands much more about each of these four caves. Our careful examination of the caves to identify features that visitors would enjoy having highlighted for them, identified features of which we were previously unaware.

Picking the Crown Jewels

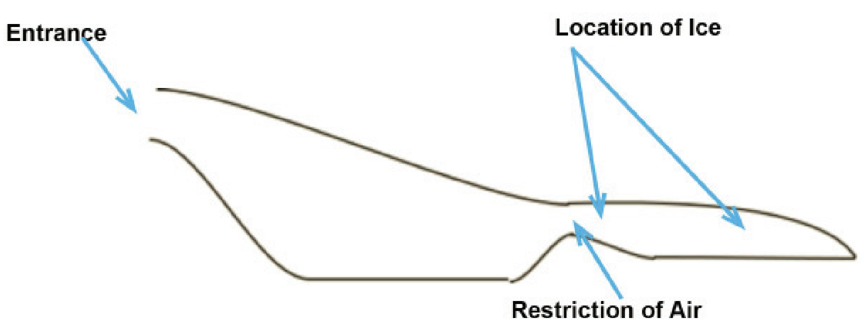
Choosing which caves and features to highlight in our virtual tours was one of the most fun parts of the project. Each of the four caves we chose illustrates certain concepts or features, based on what resource inventories had revealed about the caves. Several of the many monument caves also were popular visitor attractions until the caves were closed as a precaution against the threat of white-nose syndrome. We picked Navajo Ice Cave because of its long history of human use, including by Native Americans and early lumberjacks, both of whom needed water and found it in a cave that often contains ice year-round (Figure 2). In creating our virtual tour, we also interviewed archeologist Steve Baumann, the monument's chief of natural resources, about the use of the cave by early Americans. Short video clips of these interviews will be options in this virtual tour. The other three caves, Junction, Braided, and Four Windows Caves were picked for their bat residents, geological formations (such as in Figure 3) and their biological resources (e.g., springtails, a very small, flightless arthropod, walking on the water of small pools in the floor, and microbial mats that sparkle like jewels on the walls). This variety makes it possible to give visitors a different experience in each of the virtual tours.

Let's Take a Virtual Tour in Words

Four Windows Cave, one of El Malpais National Monument's best-known caves, is named for its distinctive four skylights. On our virtual tour, visitors will have the choice of breezing directly through the cave or stopping along the way to explore features of interest, as on a real-life tour. The proposed virtual tour starts at the Big Tubes trailhead and crosses rough lava on the approximately 1 kilometer route to the cavern. Up ahead, visitors see the large dark hole into which they will descend. Under the skylights, they see the cave's moss garden, where they can learn about the invertebrates that live there. More curious visitors also can learn about the geology of the skylights and how lava caves age. In the cave's twilight zone, the area of the caves where light from the entrance or skylights gradually diminishes to the total darkness of the deep zone, visitors can explore communities of microbes that make the walls look silvery, and look at the organisms that eat those microbes. On the cave floor, small pools are



Ah, you've noticed the ice in the cave you're currently exploring! Good observation! You may be wondering why there's ice in this cave, sometimes even in the middle of summer. The cave you're exploring is in an area that is high in elevation—over 7,000 feet. In winter, especially at night, it's cold—really cold! Cold air is denser than warm air (i.e., it contains more molecules in a given volume). So, as cold air flows into the cave it displaces any warmer air. The cave walls are made of basalt, a type of rock that is a good insulator, maintaining temperature.



The shape of the cave also helps retain the cold. The restriction in the cave, about in the middle, slows warmer air from getting into the cave due to barometric pressure changes and/or wind. So, there is a regular supply of cold air coming in during the winter and on cool nights at other times of the year. Whenever the air outside is colder than in the cave, cold air flows into the cave due to the shape of this cave, and because cold air is more dense than warm air.

Figure 2: Informational text that describes why Navajo Ice has semi-permanent ice.






Figure 3: Some of the many treasures of El Malpais caves include the terrain above the caves, the journey from light into darkness, and the ice and basalt formations found within the caves.

alive with tiny, springtails that scurry on the water's surface, occasionally using the tail-like appendage that is folded under their body, to jump when threatened. These creatures must eat something to survive, but that food source is not obvious. The virtual tourists can click on icons for answers. Traveling into the cave's dark zone, visitors will see bat bones on the floor. They can pause to learn more about bats and other cave-dwelling vertebrates. They can learn about the cave climate and the seasonal ice that is such a beautiful sight. Deeper into the cave, the passage splits horizontally, the perfect opportunity for a virtual discussion of the lava flow event that created the cave. At last, the tour climbs out through the "breakdown pile" (a pile of small to large blocks of basalt that resulted when areas collapsed during the cave formation), re-emerging on the surface in daylight again. The trail back to the entrance passes a C-shelter, blocks of `a`a basalt arranged in a C-shape and called ring structures, that were used by inhabitants of the area long ago. Pottery found in the structures suggests they may be prehistoric.

Each of the four caves in these virtual tours contains unique features; one of the caves, Junction Cave, for instance, was chosen for its bat populations.

New research is modeling the microclimate conditions in various areas of this cave, some of which are used for winter hibernation by the largest group of bats observed to date in the El Malpais caves. The researchers also are testing whether the fungus believed to cause white-nose syndrome, (Geomyces destructans), is found in these caves. (At present there is no evidence that white-nose syndrome, which has gradually been moving westward from the eastern U.S., is present in the monument caves.) Research in another of the caves, Four Windows Cave, is documenting the diversity of microorganisms that live in the lava caves. These microbial communities sometimes cover large portions of the cave walls. In the fall, these colonies repel the water that seeps into the cave, creating a sparkling silver panorama. Contributing to this phenomenon are bacteria of a type called Actinobacteria, the group from which two-thirds of the world's natural antibiotics are obtained. Many of the bacteria that scientists have found in these caves are new to science – some as new species and others as genera or even families of bacteria. Their research, and interviews with them, will enhance these virtual tours with more details likely to intrigue young and old alike.

Virtual Tours as a Management Tool

The proposed virtual tours fill a critical need. Once completed in the spring of 2013, they will be available on a public access computer at the El Malpais Information Center on route 53, southwest of Grants, NM, and in the future at the multiagency Northwest New Mexico Visitor Center, right off Interstate 40 in Grants, NM., We envision the computer providing a panorama photo of the surface above each cave, including the entrance and a brief description to allow visitors to choose the tour they wish to experience. The virtual tours will fill several needs.

With the closure of the caves because, in part, of the threat of white-nose syndrome, the El Malpais National Monument has a fundamental problem in interpreting and making accessible one of the park's major features. During this closure, the virtual tours are an exciting alternative for park visitors. In the long term, virtual tours are an interpretive alternative for disabled visitors and for those who lack the time, physical fitness, equipment or travel capability to venture into the rugged backcountry where most of the park's caves are. Virtual tours also may be useful in promoting more extended visits to the monument by allowing visitors to see what awaits them if they venture off the park's paved roads.

Another benefit in developing these virtual tours is the opportunity to learn more about these four caves and

At left, right, and above - Doing virtual technology photography in the target cave.

their resources as the tours are "built." Photographing a cave, meter by meter over three to six days, will allow the team to discover and document resources that may not have been noticed previously. The work of creating the virtual tours will be an unprecedented opportunity for scientists and National Park Service staff to work together toward common goals and products. It can stimulate new ideas and help scientists learn how to communicate better their science to the public.

The Future of Virtual Exploration

We have only partially explored the potential of computer-gaming software for making virtual tours exciting and fun. Our future efforts will explore using the 3-D shadows, incorporating avatars for "personalized" virtual cave exploration, multiple-visitor cave exploration at the same time, and expanded numbers of optional, "clickable" information presentations. We will also move the virtual tours to the Web in the second phase of development. In the third phase, we hope to obtain LIDAR technology for generating 3-D models of the caves. Testing with groups of park visitors will lead to further refinements as we learn what most engages virtual visitors. This technology offers great potential for expanding the accessibility of El Malpais National Monument resources that are otherwise challenging and sometimes difficult to explore.

Acknowledgements

We could not have done this work without the unfailing enthusiasm of **Joseph Benjamin Lopez Darrin** and the many cavers and National Park Service staff who have helped with the photography. In particular, thank you to **Pete Lindsley**, who donated his time to take a large number of the cave photographs. **Ron Lipinski** inspired this work and spent many hours explaining his methods for creating Caver's Quest. The monument staff – particularly Chief of Visitor Services **Leslie DeLong** –was invaluable. We are especially indebted to **Dr. Judy Bischoff** and the Colorado Plateau Cooperative Ecosystem Studies Unit. They helped us obtain funding from the Intermountain Region of the National Park Service. They funded hundreds of hours of our time in constructing these tours. Their aid has allowed us to bring these caves to life on the computer screen. ◘

Revealing New Triassic Microvertebrate Faunas in the Upper Chinle Formation, Petrified Forest National Park, Arizona

By Robin L. Whatley,[1] Anna K. Behrensmeyer[2] and William G. Parker[3]

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Introduction

Each year 600,000 or more visitors to the Petrified Forest National Park (PEFO) expect to see giant fossilized logs in the colorful badland topography of the Late Triassic Chinle Formation. What they may be surprised to learn is just how abundant and diverse fossil land animals are in this same rock formation (Figure 1).

Figure 1. Project co-leader and Smithsonian paleobiologist Behrensmeyer with Arizona State University graduate students Amelia Villaseñor and Luke Delezene measuring a stratigraphic section through fossiliferous rocks at Chinde Mesa in the Wilderness Area, Petrified Forest National Park, 2010. (Photo credit: R. L. Whatley)

Some of the first vertebrate fossils in the park were recognized by John Muir in 1906. In the 1921 Annie Montague Alexander, a philanthropist and naturalist who founded the University of California Museum of Paleontology (UCMP) at Berkeley, traveled to the park with her collecting partner and companion Louise Kellogg (Figure 2), where they discovered crocodile-like phytosaurs and the mammal relative *Placerias* in the Blue Mesa Member (Lubbick 1996). It was Alexander who introduced paleontologist Charles L. Camp, a new research associate at UC Berkeley and later Director of the Berkeley Museum of Paleontology, to field work in the Petrified Forest and the Chinle Formation (Irmis 2005). Over the next forty years Camp and later numerous UCMP staff and students uncovered a rich vertebrate record in the park. Interest in international biostratigraphic correlation of Late Triassic deposits in the 1980s led to renewed investigations of Chinle Formation vertebrates across the North American *southwest (Jacobs 1980*, Long and Padian 1986, for example). Work initiated in the 2000s by William G. Parker, PEFO NPS Paleontologist, has focused on relocating historic vertebrate localities (Parker 2002; Parker

Figure 2. Annie Alexander, Louise Kellogg, and Eustace Furlong (preparator) examine a phytosaur skull in Saurian Valley in 1921. (Photo credit: University of California Museum of Paleontology)

and Clements 2004), collecting and describing medium to large-sized vertebrates (Parker and Irmis 2005; Parker et al. 2005) and unraveling the complex lithostratigraphy within the park (Martz and Parker 2010, Parker and Martz 2011). In addition to Parker's own paleontologic investigations, and largely resulting from his and the Resource Management Director, Pat Thompson's efforts to facilitate research in the park, a number of additional teams have joined the search for new vertebrate fossils. In addition to our project, led by authors Whatley and Behrensmeyer, paleontologists from Yale University, the Los Angeles County Museum, and the University of Texas at Austin regularly conduct field projects within the park. Current paleontological research is building upon over a century of research in the Chinle Formation of PEFO, which is recognized as one of the most complete Late Triassic successions of terrestrial deposits and fossils in the world, spanning ~225 to ~205 million years ago.

Late Triassic World of the Petrified Forest National Park, Arizona

The earliest ancestors of mammals, lizards, crocodylomorphs, turtles and dinosaurs originate and diversify in the Late Triassic through Early Jurassic (~225 – 180 Ma). Sedimentary deposits in the American southwest have produced the oldest known (Late Triassic) North American mammal, *Adelobasileus cromptoni* (~225–206 Ma; Lucas and Luo 1993). A later diverse small vertebrate fauna from the younger Kayenta Formation, Arizona (~200 – 180 Ma), includes early mammals, non-mammalian synapsids, lepidosauromorphs (lizard ancestors), turtles, crocodylomorphs, amphibians, and ornithischian dinosaurs (Jenkins et al. 1983; Sues et al. 1994; Behrensmeyer and Whatley 2008). The upper sedimentary deposits in the PEFO are intermediate in age between these two important mammal-bearing intervals and represent a time when mammals and other small land-dwelling vertebrates diversified in North America (Ramezani et al. 2011; Parker and Martz 2011). In the Chinle Formation fauna of PEFO, dinosaurs are present but uncommon (Parker et al. 2006), while pseudosuchians and other archaic large tetrapods are relatively abundant (Long and Murry 1995), indicating that the 225 - 205 Ma time period represents a critical transition to the dinosaur-dominated ecosystems that followed.

Paleontologic investigations in the Owl Rock Member, Wilderness Area

The Chinle Formation in the PEFO represents one of the most complete records of Late Triassic vertebrate evolution. Research in PEFO has contributed a large body of information on fossil trees and large vertebrates, but less work has been done on microvertebrates. These are the fossil remains of small vertebrates such as early mammals, lizard ancestors, small amphibians or juvenile vertebrates that would typically have less than 1 kg of live body weight.

Our larger project goal is to discover and study new fossil assemblages that will lead to understanding the taphonomy (mode of death and fossilization) and paleoecology of small vertebrates of the Late Triassic time period, when many groups of land animals including mammals and dinosaurs originated and began to diversity. Only three of several hundred publications on the paleontology of PEFO report on microvertebrates (Long and Padian 1986; Murry 1989; Heckert 2004), and none of these focus on the youngest deposits in the park, the Owl Rock Member of the Chinle Formation. Fossil vertebrates are known from the Owl Rock Member elsewhere in northern Arizona (Kirby 1991, Spielmann et al. 2007) and southeastern Utah (Fraser et al. 2005, but prior to our investigations fossils were not known from this unit in the park. With the addition of new PEFO land acquisitions, little-known deposits like the Upper Petrified Forest Member and the overlying Owl Rock Member in the upper part of the Chinle Formation are now available for study.

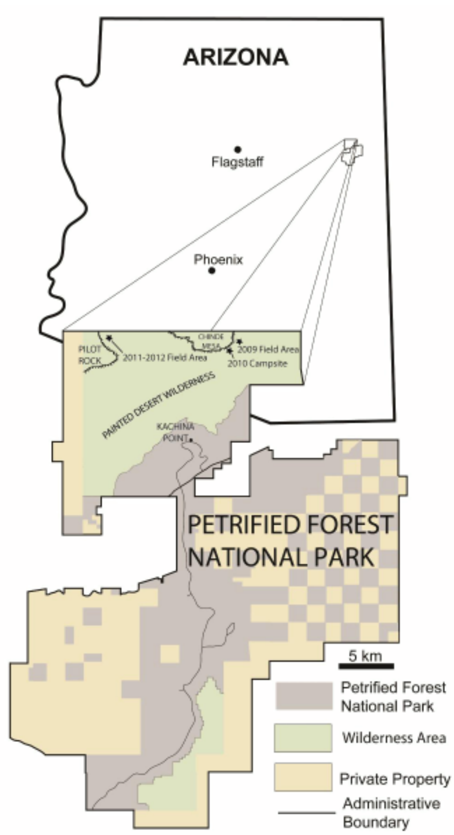

Figure 3. PEFO Map; our field areas are in the Wilderness Area in the northern part of the Park.

As part of a larger research project to investigate early mammal diversification and ecological complexity, we initiated surveys of the youngest fossiliferous deposits in the upper Petrified Forest Member and the Owl Rock Member, which are exposed in the Wilderness Area near the northernmost park boundary and dated to a time when early mammal fossils are known to exist elsewhere (Figure 3). Our primary objective is to locate microvertebrate fossil sites that can be surface collected, quarried, and/or screen-washed, with the aim of identifying the kinds of small animals (including early mammals) that existed in the Late Triassic and the environments where they were preserved. These types of animals would have been integral components of the food webs that also supported early dinosaurs, and our research is contributing new data allowing more comprehensive reconstruction of late Triassic ecosystems.

Our efforts have been focused on reconnaissance of the uppermost sedimentary deposits near the northern boundary of PEFO. These deposits are in a designated Wilderness Area where motorized vehicles are prohibited, in an effort to reduce the impact of humans on native habitats. During the park's early history, automobiles were an important means of exploring, and in some cases exploiting the resources within the park, for both visitors and

Figure 4. 2010 Field Crew prepares to depart for Chinde Mesa. Left to Right: James Meyers (Columbia College, Chicago), Larry Shepherd (Padres Mesa Ranch), Bill Inman, (Padres Mesa Ranch Manager), Kay Behrensmeyer, (Smithsonian Paleobiologist, co-leader), Bill Amaral (Harvard University) Luke Delezene, Amelia Villasenor, (Arizona State University), Gene Shepherd (PMR), Robin Whatley (Columbia College, Chicago and co-leader with Behrensmeyer), Anderson White (PMR). (Photo credit: Petrified Forest Museum Association)

Figure 5. Sedimentary deposits of the White Channel Complex (WCC) are seen here capping the top of the buttes in the foreground at right. Inset: Examples of fossils found in the WCC, *Revueltosaurus*" sp.; d. Actinopterygian fish tooth, and e. fish scale; f. well-preserved tooth from micro-excavation of WCC matrix. (Photo credit: Paloma Whatley; Fossil images captured by Suzy McIntire, Smithsonian Institution.)

paleontologists. Our target collecting area was about 7 miles from a major interstate highway - too far for daily walks with necessary supplies and water… To meet the challenge of working in the Wilderness Area, we returned to old style paleontology and the employ of horses to pack in our supplies, equipment and water and to carry out the fossils we collected for study. Working in a Wilderness Area is a challenge without vehicles, but not an insurmountable one (Figure 4).

In 2009 and 2010, we surveyed the southern and eastern facing exposures at Chinde Mesa. In 2011 and 2012 we expanded our search to the northwest boundary of the PEFO at the base of Pilot Rock. We recorded over 200 new fossil localities at four levels of the Owl Rock and Petrified Forest Members in the first three field seasons, and in 2012 more thoroughly investigated especially fossiliferous deposits discovered in 2011. Our discoveries include the youngest and first known vertebrate fossils from the Owl Rock Member in the Park. They also represent biostratigraphic range extensions for *Revueltosaurus*, metoposaurs including *Apachesaurus*, theropod dinosaurs, and aetosaurs (Whatley et al. 2011).

In 2011, we discovered the "White Channel Complex (WCC)," a fossiliferous sedimentary deposit up to 3 m thick that can be traced over an area of several km^2 (Figure 5). This deposit represents the partial filling of a channel system by volcanic sediment that includes zircons, which have been dated using $^{206}Pb/^{238}U$ decay rates (J. Ramezani, personal communication 2011, manuscript in preparation). We collected blocks of matrix from one locality in this layer to test preparation methods at the National Museum of Natural History (NMNH), and these have produced abundant and well-preserved skeletal and dental elements of phytosaurs, fish, amphibians, theropods, the archosaur Revueltosaurus, as well as new discoveries of vertebrates that are otherwise especially rare in Late Triassic deposits of western Pangaea (manuscript in preparation). The pristine state of many of the teeth and small bones in this deposit indicates that they were derived from both land and aquatic habitats associated with the channel ecosystem (Behrensmeyer et al. 2011). Discoveries elsewhere demonstrate that early mammals existed in North America at this time, but none are known so far from PEFO or the Chinle Formation; our methods should either recover their remains or provide evidence for why they were rare to absent in these archosaur-dominated paleocommunities of the latest Triassic.

Field and Laboratory Methods

For our field research in PEFO, we focused on the collection of fossils representing small vertebrates. Because our aim was to understand the small vertebrate communities, we collected specimens and geological information in order to document taxon

Figure 6. Microvertebrate collecting methods, clockwise from top left: Amelia Villaseñor searches for tiny bones and teeth on the surface, William Amaral prepares a matrix block for removal from the WCC with the 2012 crew, and Guru Das Bock, A. K. Behrensmeyer, and Jesse Krug inspect surface sediment for bagging (bottom left). (Photo credits for 1 and 2: A. K. Behrensmeyer; 3: R. L. Whatley)

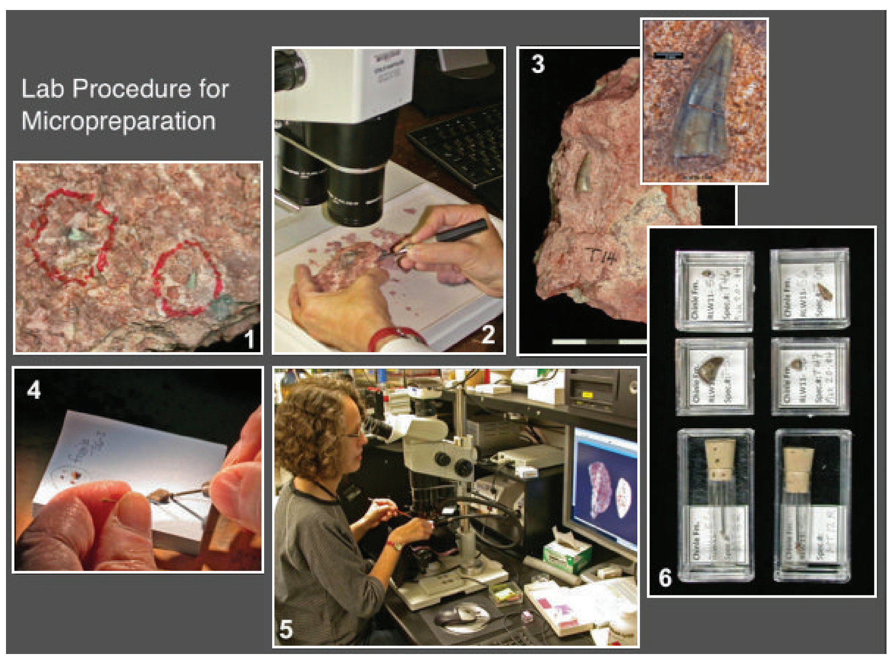

Figure 7. Lab Procedure for micropreparation: 1) Examine and mark matrix. 2) Expose with pin vise under microscope and repair and glue if necessary, with the help of camel hair or cat whisker. 3) Photograph in matrix to show micro-context. 4) Remove for fine preparation, using Post-it adhesive surface to control small teeth or bones. 5) Label, photograph through a stereo zoom microscope (Volunteer Suzy McIntire at the Smithsonian). 6) Store and continue excavation until block is finished.

co-occurrences, spatial and geographic distribution of bones and assemblages, preservation, depositional environment and stratigraphic information from *in situ* material.

Most of the fossil vertebrate remains discovered so far in the Owl Rock Member are small and/or fragile, requiring special methods for collection and preparation. Early tests of dry and wet screening of sediments with small, delicate specimens showed that this standard method for recovering microvertebrate remains was too destructive. Our methods include surface collection, bagging of sediment, and extraction of blocks of fossiliferous rock for picking and preparation under a microscope (Figure 6). This approach to these deposits has opened a new "taphonomic window" on abundant remains of small vertebrates as well as fragmentary remains of larger taxa, but it also has demonstrated that many of these can only be recovered with specialized preparation methods.

Blocks have been collected for micro-excavation in the NMNH Preparation Laboratory and the public exhibit "FossiLab" at the Smithsonian (Figure 7). Expert volunteers do the initial excavation, cataloguing and photography; professional NMNH technicians then take on specimens requiring specialized preparation. Micro-preparation is necessary to discover the best-preserved fossils contained in the quarry blocks. Many of the smaller fossils are not visible without the aid of a microscope, and their fragility (many are extensively cracked), requires consolidant hardeners so that they can be prepared without disintegrating.

We are also comparing museum specimens from the Upper Petrified Forest and Owl Rock members that were collected by earlier researchers outside the park to fossils we have collected to make identifications. In Spring 2012, we worked in the Museum of Northern Arizona's Chinle Formation collections, and in Fall 2012, Whatley was Scientist in Residence at the PEFO Headquarters. During that time vertebrate fossils housed in the park collections were examined as well as additional fossils from the Owl Rock Member at the Museum of Northern Arizona.

2009 – 2010 Field Work at Chinde Mesa, Wilderness Area, PEFO

The core team of Whatley, Behrensmeyer and William Amaral (retired Harvard University micro-preparator) conducted initiated field reconnaissance in 2009 in previously unexplored deposits in the Wilderness Area at the northern boundary of the Park. We were also joined in the field by Parker and PEFO interns Chuck Beightol and Rachel Guest. Limited surface prospecting yielded 27 new fossil localities in the uppermost Petrified Forest and Owl Rock Members near Chinde Mesa. Following up on this encouraging start, we returned in 2010 with a six-member team consisting of Whatley, Behrensmeyer, Amaral, James Meyers, an undergraduate film student from Columbia College Chicago who documented our work for both research and educational purposes, and Amelia Villaseñor and Luke Delezene, graduate students from Arizona State University.

For our 2010 expedition we planned more intensive surveying in the upper Chinle Formation outcrops at Chinde Mesa. Our target area was located at the northernmost boundary of the PEFO in the Wilderness Area and a ~6 mile walk from the nearest vehicle access point (see Figure 2). With help from the PEFO administrators we were able to meet with employees of the Padres Mesa Demonstration Ranch (PEFO neighboring lands on the eastern boundary). Gene Shepherd and Anderson White, experienced Navajo wranglers, were hired with their horses to pack in our food, water and gear to a designated camp at Chinde Mesa in May

Figure 8. Navajo wranglers, Anderson White (shown here) and Gene Shepherd helped us get water and gear into the difficult terrain of the Wilderness Area. Fossils and fossiliferous matrix was packed out by the mule (shown here) and a strong black mustang. (Photo credit: A. K. Behrensmeyer)

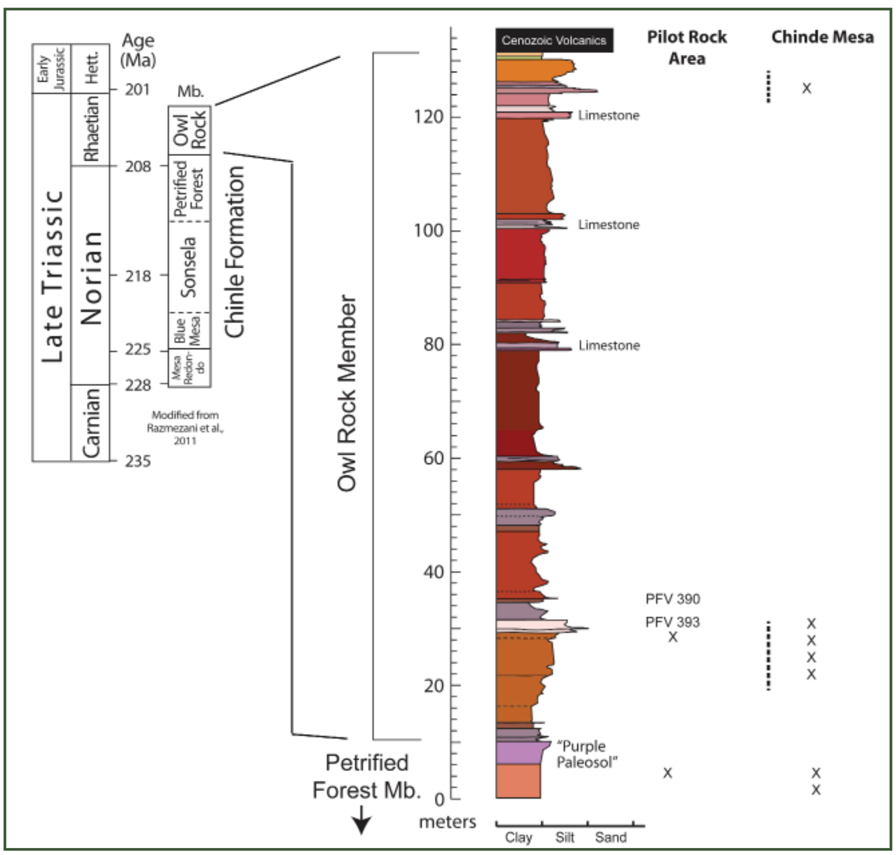

Figure 9. Stratigraphic column showing the positions of new localities in the Owl Rock Member, Chinle Formation, Petrified Forest National Park, including the White Channel Complex locality, PFV 393.

2010 (Figure 8). Our crew hiked the 6.5 miles from the Painted Desert Inn at Chinde Point to the base of Chinde Mesa and set up camp ("Chinde Camp") at a prominent wash on the south face, from which we conducted fieldwork each day.

During this time we discovered 38 additional new fossil localities, increasing the number of known fossil localities in the Owl Rock Member to a total of 41 sites. These localities, some of which also yielded plants, bivalves and gastropods, represent both the youngest vertebrate fossils in the Park and the first recovered from the Owl Rock Member in the Park. In addition, we conducted controlled lateral surveys ("Bone Walks") along specific stratigraphic intervals to locate additional fossil-producing sites, and we measured detailed stratigraphic sections of the fossiliferous localities and strata (Figure 9).

2011 – 2012 Field Work in the northwest Wilderness Area, PEFO

In 2011, a seven-person crew consisted of Whatley, Behrensmeyer, Amaral, Villaseñor (now a graduate student, George Washington University), Ben Miller (undergraduate student and intern, Smithsonian Institution), and Paloma Whatley (freshman high school student and niece of R.Whatley) and

Andrew Du (graduate student, George Washington University). William Parker and two PEFO interns (Rachel Guest and Susan Drymala) joined our crew to prospect on two separate days during the field season. Our camp was located on a PEFO service road just inside the park boundary fence overlooking sedimentary exposures.

We discovered 62 new fossil localities using traditional prospecting methods in 2011, as well as additional localities (N=81) that were collected from as part of three standardized "Bone Walk" transects, for a total of 143 new fossil localities (Figure 10). These sites produced hundreds of fossils, including matrix samples for picking and sediment blocks for micro-preparation from a quarry within the productive and laterally extensive "White Layer" in the lower Owl Rock Member. More small fossils are being discovered daily in the "FossiLab" at the National Museum of Natural History, where volunteers pick through surface matrix and excavate matrix blocks where they can be observed by the public. Over 250 small tooth and bone specimens are now catalogued from these micro-excavations, and many have been photographed (Figure 5).

The three controlled Bone Walk surveys in 2011 documented all fossils found along specific stratigraphic levels. The first of these (BW11/1) was initiated at fossil locality PFV 390 in the Owl Rock Member where 62 bone occurrences were recorded (of these many were unidentifiable bone fragments and therefore not collected). BW11/1 yielded significant fossils that were collected from 33 new localities. Some of the fossils recovered include vertebral elements from a small temnospondyl amphibian, reptile pelvic bones and teeth, and at least three small jaws fragments, one with three tiny teeth. Bonewalks BW 11/2 and BW11/3 were conducted in the upper part of the Petrified Forest Member pink to purple paleosol beds, with 68 bone occurrences recorded and significant fossils collected from 48 new localities. Fossils included small temnospondyl skull and jaw elements, many osteoderm fragments, a partial phytosaur jaw, and fragile, but beautifully preserved reptile vertebral elements, many of which are bright turquoise from the mineral vivianite, a result of the formation of iron phosphate during mineralization.

Figure 10. Close surface prospecting is required to locate small vertebrate fossils during a Bone Walk at Locality PFV 390 in 2011. Left to right: Rachel Guest, Ben Miller, Villaseñor, Paloma Whatley, Susan Drymala, Andrew Du, W. Parker, and A. K. Behrensmeyer. (Photo Credit: R. L. Whatley)

Our 2011 field work identified several new stratigraphic levels that contain fossil remains (see Figure 9):

1) The PFV 390 layer, which represents channel and channel fill deposits that are well-exposed along strike and relatively fossiliferous.

This level is about 4 meters above the "White Channel Complex" or "White Layer" (see below).

2) The "White Channel Complex" (also known as the "White Layer"), conglomeratic matrix with a poorly sorted mix of rounded mud pellets, carbonate clasts, angular to rounded rock fragments, and medium to fine sand (includes PFV 393). This lithology is laterally continuous over hundreds of meters and may represent fluvially reworked channel and floodplain deposits.

3) The purple paleosol interval below the Pastel Beds Complex that marks the uppermost Upper Petrified Forest Member at the contact with the Owl Rock Member (pers. com. J. Martz, W. Parker), which produces blue vivianite bones, osteoderms and other well-preserved small vertebrate remains.

Behrensmeyer, with help from graduate students Du and Villaseñor, measured a stratigraphic reference section in 3 parts, totaling over 120 meters. This spans the whole Owl Rock Member in the Park and the upper part of the Petrified Forest Member, allowing localities to be tied to specific stratigraphic levels within this section. Du also collected samples of the White Layer that were processed for radiometric dating at MIT.

In Spring 2012, we conducted a 1-week field project involving intensified survey of the White Layer to document variability in preservation and identify parts of this deposit that have more complete remains of small animals. In addition to Whatley, Behrensmeyer and Amaral, University of Oklahoma graduate student Jenna Domeischel (who conducted an Undergraduate Research Mentor Initiative project on bivalves from the Owl Rock Formation, PEFO with Whatley at Columbia College Chicago), and Guru Das Bock and Jesse Krug, undergraduate students from the University of Arizona, joined us in the field. Four test sites within the white layer were targeted for limited excavation and additional surveying, and particularly promising matrix blocks were collected for further examination and preparation at the NMNH.

Our preliminary results indicate marked environmental change through the upper part of the Chinle Formation in the PEFO (upper Petrified Forest Member and Owl Rock Member). Large phytosaur fossils and aquatic invertebrates are common in the Pastel Beds, near the contact between the Owl Rock and the Petrified Forest Member, but rare in the upper Owl Rock deposits surveyed at Chinde Mesa in

2009-2010. This suggests a decrease in aquatic habitats upward in the section, at least locally. This pattern is further supported by a decrease in paleochannels and an increase in fine-grained, pedogenically modified sediments through the Owl Rock Member. In 2011, we found abundant phytosaur skeletal and cranial elements in the Petrified Forest and lower Owl Rock Member deposits in the vicinity of Pilot Rock, ~4 miles (~6 km) from our collecting area at Chinde Mesa, but no evidence of fossils above the lower part of the member. Bivalves and gastropods also are abundant in the top of the Petrified Forest Member with at least one approximately 1 meter thick layer of recrystalized bivalves occurring below the pink/purple beds, but we found no bivalves above the Petrified Forest Member near Pilot Rock, and gastropods are rare. The sediments in the upper two-thirds of the Owl Rock Member are remarkably homogeneous and fine-grained, with occasional carbonate layers, superimposed paleosols, and few paleochannels. The pattern of decreasing aquatic habitats through time thus is similar at both Chinde Mesa and Pilot Rock. The micro-fauna is diverse in the lower Owl Rock Member (archosauriforms, fish, amphibians, dinosaurs), and the fact that we have not found any mammalian remains suggests that this group was rare to absent in the Upper Triassic habitats represented by the PEFO deposits; this hypothesis of course is subject to further testing.

NPS Involvement and Value to Public

PEFO was established to preserve and study fossil resources from the Late Triassic interval. One of the main park goals is to understand the geological and paleontological history of the park and how it pertains to other Triassic units globally. Historically early work and resource protection in the park has focused on the prevalent fossil wood; however, the majority of this wood is found in only a single layer in the formation. Thus, while aesthetically pleasing and interesting because of its sheer volume, fossil wood tells us very little about the Late Triassic biota and its evolution through time. The Triassic is significant because it represents the time when the first turtles, lizards, crocodiles, dinosaurs and mammals appear in the fossil record. Not surprisingly fossils of these animals are very poorly known, mostly because their small size renders them difficult to discover through normal paleontological prospecting methods. Screen washing, or as in this case, careful and inspection of fossiliferous sediments under a scope and micropreparation, especially those from poorly searched geologic members, has the potential to be more successful in finding these types of fossils. The NPS currently does not have the staff or the logistical ability to conduct this type of research, especially in the northern portion of the park. Therefore, the NPS is motivated to establish research partners such as the Principle Investigators in this project to accomplish this goal. Furthermore, our project greatly assists with the natural resource inventories for geology and paleontology in the northern third of the park, which had not been previously explored.

For this project PEFO has provided logistical support including lodging/camping, storage, maps, literature, fossil identification and curation assistance. Furthermore, the Petrified Forest Museum Association has provided some matching funding for resources from Columbia College Chicago and the Smithsonian Institution (National Museum of Natural History). The NPS Research Coordinator, Judy Bischoff, from the Colorado Plateau Cooperative Ecosystem Studies Unit provided two years of funding support for this project.

Picking of PEFO 2010 fossil-bearing matrix, using a microscope with a wide-format viewing screen, has become a very popular activity for the NMNH "FossiLab," a working preparation laboratory on view to the public (NMNH has over 7 million visitors per year). Volunteers frequently interact with visitors, answering questions and providing information about the roles of the Museum and the National Park in conserving and assisting with research on the fossiliferous deposits.

Conclusions and Future Work

Through specialized methods of collection and micro-preparation, we are opening new taphonomic windows on the diversity of life that inhabited Late Triassic landscapes.

Our research is part of a larger effort to improve knowledge of vertebrate diversification and ecological complexity in early Mesozoic communities represented in the park and in North America. Once we have inventories of the taxa present at multiple excavated sites, we will be able to reconstruct ecological aspects of each assemblage. These include: major groups present, number of distinct taxa, trophic diversity, body size diversity, relative abundance (e.g., based on teeth), and taphonomic characteristics including body parts, condition of fossils, sedimentary context, etc. We will compare taxonomic lists and abundances from different contemporaneous sites to characterize the paleocommunities of that time interval and then compare these in different time intervals, including older sites in the Petrified Forest and Sonsela Members.

Significance

The youngest rocks in the Chinle Formation in PEFO preserve a time interval (latest Norian – Rhaetian stages) important for understanding the evolution of the ancestors of modern groups such as mammals, lizards, crocodylomorphs, turtles, dinosaurs, and amphibians, as well as the decline of previously dominant archosaurs and therapsids. Radioisotopic dates from volcanic deposits within the park represent one of the few Late Triassic sequences in the world with calibrated biostratigraphic range data against which other datable deposits can be correlated (Ramezani et al 2011; Parker and Martz 2011). Our field program is contributing new fossils and taphonomic data to efforts to understand vertebrate diversification and ecological complexity of early Mesozoic communities in North America and other continents during a critical time in the evolution of land vertebrates and ecosystems. ◘

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Feature Program— Environmental Quality

By Chris Turk, Chief of Environmental Compliance - Retired

Do you wonder how to make sound resource-based decisions on your park plans and projects? The environmental compliance process is the foundation of every project, from the beginning of an idea to full-scale implementation. Whether the project is simple or complex, environmental compliance is involved. The Intermountain Region's Environmental Quality Division helps parks find their way through laws such as the National Environmental Policy Act (NEPA) and Section 106 of the National Historic Preservation Act (NHPA).

The region's EQ team is dedicated to helping you accomplish your environmental quality goals by providing technical assistance, professional expertise, and training. This committed team of four includes the regional Environmental Quality coordinator (vacant); Laurie Domler and Cheryl Eckhardt, environmental compliance specialists; and David Hurd, an environmental compliance technician.

On a day-to-day basis, EQ answers your questions on how to comply with NEPA, Section 106 of NHPA and other environmental quality laws, regulations and policies. The team helps parks start the environmental compliance process by initiating the Environmental Screening Form (ESF), leading them through internal scoping, and determining the appropriate levels of compliance. Team members can show you how to enter projects into the Planning, Environment, and Public Comment (PEPC) system to track project compliance, mitigation and tasks and to accept and analyze public comments.

NEPA/106 Specialists Laurie Domler and Cheryl Eckhardt

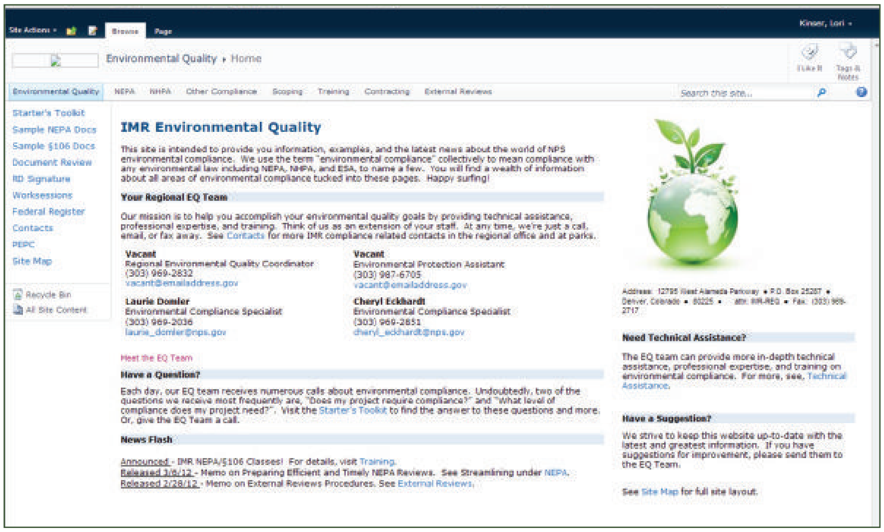
All environmental assessments (EAs) and environmental impact statements (EISs) are reviewed by the EQ office before they are released for public review. Getting to the review stage is easy: post the documents to PEPC and send an email to the team requesting review. Please address the email to all team members so that if one is out of the office, another can review it for you. If you want a resource specialist to review the document as well (e.g. air resources, soundscapes, etc.), please specify that in the email. The EQ team requests at least 10 business days for this review, but often completes the review in less time. For General Management Plans or other lengthier documents, the team may need a full month to review. The team will upload its comments to PEPC and notify you by email when the review is complete. The team asks that you consider its comments before releasing the document for public review.

The EQ team also is happy to review any other compliance-related documents, including public scoping brochures, categorical exclusions, scopes of services, cost estimates, project agreements and cooperating agency letters, to name a few. Email the team members about what type of review you seek and they will let you know whether you should post it in PEPC or email it directly to the team.

In addition, the team helps parks process documents for the IMR regional director's signature, including decision documents and Federal Register notices. EQ also will help you prepare and enter documents into the Department of Interior system and track Federal Register notices for environmental documents.

On a longer-term basis, the EQ team assists parks with requests for technical assistance. These requests can range from conducting internal scoping to serving as project liaisons or project managers (contracting officer's representative). EQ develops public involvement strategies tailored to your project and can analyze public comments. Team members help guide you through the steps in the environmental compliance process so you can make better resource-based decisions.

The EQ team maintains a website (currently under construction) with additional information to help make your compliance process easier. There, you can find the latest examples of documents, including a sample EA, agency consultation letters, and public scoping brochures. You can also find the latest news



and guidance on numerous compliance-related matters such as impairment and instructions for how to process Federal Register notices. Contact one of the EQ team members for the link.

EQ connects IMR parks with projects happening outside their boundaries, too. This is known as the External Review Program, in which the National Park Service has the opportunity to review and comment on what other agencies are doing that may affect our parks. The EQ team serves as lead for this process in the IMR to help parks process these comments so ultimately NPS and DOI can respond back to the agency in a unified voice.

To help parks better understand compliance responsibilities and processes, the EQ team conducts some classroom workshops each year on NEPA and NHPA Section 106. These workshops are designed for everyone from beginners to experts. When feasible, the team makes the training available at parks to encourage interaction among park staff on environmental compliance and to help ease the burden of cost and travel constraints. The team is looking into hosting additional training opportunities.

As the director of the Park Service pointed out when Director's Order 12 was issued: "Planning, environmental evaluation, and public involvement in management actions that may affect NPS resources are essential in carrying out the trust responsibilities of the National Park Service." The EQ team is here to help you every step of the way. ◘

People Notes

What's happening with our most important resource; our people...

Like the change that has become the "new normal" for the nation, so too has the RSS Directorate experienced change among its ranks. We said goodbye to a handful of faces that have worked with us for many years, for some folks even decades.

Sande McDermott, former Intermountain Region assistant regional director for Cultural Resources, left in the summer of 2012 to become deputy associate director for Cultural Resources in the NPS Washington office.

Virginia Salazar-Halfmoon, Sande's Vanishing Treasures program manager, retired at the end of 2012.

Four colleagues in Natural Resources – **Bonnie Semro**, the funding and data coordinator, and **Suzy Stutzman** the region's wilderness coordinator – also retired at year's end, along with **Larry Norris**, DS-CESU Research Coordinator and **John Reber**, Physical Resource Program manager.

Chris Turk, the directorate's chief of compliance, retired in February 2013.

Collectively, these veteran colleagues had decades of service with the National Park Service, many of those years in the Intermountain Region.

John Wessels

John Wessels, Regional Director, Intermountain Region, left the NPS on August 24, 2013 after 14 years of service; the last three as Director of the IMR. John accepted a position with the American Battle Monuments Commission to serve as the Director, Overseas Operations, headquartered in Paris, France.

New Faces

This year the directorate also welcomed a number of new folks...

Michael Bozek, is the IMR's new chief of Inventory & Monitoring.

Also joining us are:

Tom Lincoln – Cultural Resources.

David Vana-Miller, Randy Stanley, Donna Shorrock, and Nate Ament – Natural Resources.

David Hurd – Environmental Quality.

Victoria Campbell-Smith – Geographic Information Systems.

Jenny Hauer – Colorado River Basin.

Chris Turk retired with 35 years of NPS service.

Michael Bozek, Chief of Inventory and Monitoring

Thomas Lincoln, Associate Regional Director – Cultural Reources

Montezuma Well

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Crossroads in Science

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