WEATHERING THE STORM: DIAGNOSTIC MONITORING FOR PREVENTIVE CONSERVATION AT SPRUCE TREE HOUSE, MESA VERDE NATIONAL PARK, COLORADO

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A THESIS in Historic Preservation Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements of the Degree of MASTER OF SCIENCE IN HISTORIC PRESERVATION 2009

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Abstract
This paper examines Spruce Tree House, an alcove site located in Mesa Verde National Park, as a model for monitoring the impacts of the natural environment on the deterioration of a unique collection of archaeological resources. At present, it is the only alcove site in the park that has been fully documented by park service archaeologists. In the past, preservation at Mesa Verde has focused on the minimal remedial stabilization of the prehistoric masonry structures. A comprehensive study of broad deterioration patterns across the alcove sites in the park and the possible causes of these patterns has never been performed. Identifying common sources of deterioration site-wide has the potential to lead to a comprehensive maintenance plan that could slow deterioration through preventive as well as remedial actions, thereby protecting the resources and decreasing the amount of emergency rehabilitation work needed. Implementation of a monitoring program is the first step in this process, as it allows us to identify patterns and establish causality, leading eventually to non-invasive preventive and protective measures. This paper proposes that the presence of water is the main cause of deterioration at the site. A specific monitoring program has been put forth in order to verify that this is still an active problem at the site. The program includes the use of soil moisture meters, motion activated cameras and at least one weather station to record the external environmental conditions for comparison with occurrences within the alcove.

Comments
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A THESIS

in

Historic Preservation

Presented to the Faculties of the University of Pennsylvania in
Partial Fulfillment of the Requirements of the Degree of

MASTER OF SCIENCE IN HISTORIC PRESERVATION

2009

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To my grandmother, who taught me that learning is its own reward. And to Zayde, who knew that all of the problems of the world could be solved with patience, hard work and a sense of humor.
ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Michael C. Henry without whose guidance this thesis would never have been possible. Thank you for encouraging me to think outside the box and for always challenging me, no matter how I resisted.

Thanks also to my family, who has supported me throughout this process. They continue to provide encouragement, a sympathetic ear, a shoulder to cry on, or a truly terrible joke or song, as needed.

Professors Frank Matero and Randy Mason, along with the staff and faculty of the Graduate Program in Historic Preservation at the University of Pennsylvania have bestowed upon me a wealth of knowledge that continues to broaden my experience and prepare me for whatever obstacles may arise in my future career.

Scott Travis, Kay Barnett, Robert Jensen, Julie Bell, Gay Ives, Preston Fisher, Greg Cox and Donna Glowacki frequently went out of their way to help me during the summer spent at Mesa Verde and during subsequent research. Sincerest thanks to you all.

Thank you to Julie, Ariana and Alden, for sticking with me through thick and through thin, and for indulging me in those pursuits I most adore.

Finally, I owe a debt of gratitude to my fellow classmates, who truly, truly understand.
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CHAPTER 1: INTRODUCTION

This thesis considers Spruce Tree House, a large thirteenth century Ancestral Puebloan alcove site in Mesa Verde National Park, as a model site for monitoring the impacts of the natural environment on the deterioration of an alcove site’s architecture and its associated archaeological resources. Research includes a review of current conditions at the site and the formulation of hypotheses as to the causes of these conditions. Monitoring tools and methods are then explored for the purpose of validating the hypotheses, thereby setting the stage for developing measures to mitigate the impacts of the complex and interwoven systems of deterioration at the site.

1.1 Justification

Mesa Verde National Park contains over 4000 known archaeological sites and some of the best-preserved alcove sites in the country. Designated by President Theodore Roosevelt as part of the 1906 Antiquities Act, Mesa Verde was the first National Park in the United States created with the express purpose of protecting and preserving “the works of man.” Active excavation is not currently taking place in the park, and archaeology has recently focused on mapping and documentation of both front-country and backcountry sites. In the past, preservation of the built environment at these sites has consisted of minimal remedial stabilization of the masonry structures. A comprehensive study of broad deterioration patterns across the alcovate sites in the park, and the possible causes of these patterns, has never been performed. Identifying common

sources of deterioration site-wide has the potential to lead to a comprehensive maintenance plan that could slow deterioration through preventive as well as remedial actions, thereby protecting the resources and decreasing the amount of stabilization and emergency rehabilitation work needed.

As the only alcove site in the Park open to the public without a ranger-guided tour, Spruce Tree House has high visitation; as many as several thousand people per day visit the site during the summer months.³ It is the second largest alcove site in the park with the highest percentage of intact, original fabric,⁴ making it an ideal site to use as a model for monitoring the effects of weather and the environment on its deterioration. Spruce Tree House is representative of many of the other alcove sites in the park and has been well documented by National Park Service archaeologists on staff at Mesa Verde.

1.2 Research Methods

Understanding the history of Spruce Tree House is paramount before any program of observation or intervention can be implemented at the site. Thus research began with a thorough review of archival information about the site, including textual and visual documentation of its excavation and intervention history. Archival research was followed by a brief site visit in January 2009. During this visit existing conditions were documented and photographed and preliminary hypotheses as to their causative

mechanisms were developed. Upon returning from the site in late January, further research was undertaken to refine the hypotheses and to learn about existing tools and methods of monitoring. A potential monitoring plan with the aim of validating hypotheses regarding causative mechanisms of deterioration was then developed.

1.3 Limitations

Several circumstances constrained the scope and detail of this thesis. The most difficult limitation was the absence of a conditions report for Spruce Tree House alcove site. The Archaeological Site Conservation Program (ASCP) was established by Mesa Verde National Park in 1996 as a system of documentation and preservation aimed at carefully recording all archaeological sites in the park for future generations. The ASCP consists of three steps, which are to be completed sequentially:

- **Site Survey**-baseline collection of data for every site including sketch maps, photographs and a GPS location
- **Condition Assessment**-assessment of standing walls for damage due to water, fire, structural instability and rodents.
- **Architectural Documentation**-thorough and detailed graphic record of standing architecture including photographs and stone-by-stone measured drawings. Includes field forms to record construction attributes and features.

In the fall of 2008 archaeologists at the park discovered that for unknown reasons the second step in the ASCP for Spruce Tree House had been omitted. A site survey had been completed as well as in depth architectural documentation resulting in a 300-page report published in 2007. As a result of the omission, there is currently no detailed

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6 Ibid.
documentation on prior conditions with which to compare the current conditions. Comparison of existing conditions with past conditions would have been one of the most useful methods of gauging whether deterioration activity at the site is active or passive. A more in depth and methodical conditions assessment will need to be performed for Spruce Tree House alcove if future deterioration is going to be monitored and subsequently managed.

Another limitation to the scope and detail of this thesis was inaccessibility to the site during the research period. Only one site visit was possible due to time and financial constraints. While important observations were made during this visit, all subsequent observations were made using notes and photographs brought back from the site. This precluded any opportunity to view conditions over time or to confirm assumptions made from photographic evidence. Therefore all observations and hypotheses based on those observations are a result of conditions viewed over just a few days. The short site visit also limited the amount of time spent in the Mesa Verde archives, where a good deal of information is housed dealing with past stabilization and intervention campaigns.

Despite these limitations, this thesis presents a thorough description of current conditions at Spruce Tree House and presents plausible, if only preliminary, hypotheses as to their causes. These causes must be confirmed and systematically monitored if the Park Service wishes to slow deterioration at one of their most important sites. The plan presented in this thesis will allow Park Service staff to develop cost-efficient and informative monitoring methods to better inform future interventions.
CHAPTER 2: SITE ORIENTATION

2.1 Mesa Verde National Park

2.1.1 Location

Mesa Verde National Park consists of about one half of a large plateau in the southwestern corner of Colorado. The plateau was named Mesa Verde, or “Green Table,” by early Spanish explorers because of its year-round covering of Pinyon and Juniper forest. The park itself encompasses 52,121 acres and has an average elevation of approximately 7,000 feet.

European explorers first saw Native American ruins in the area as early as the middle of the 18th century. However, it was not until the late 1880s that the first “cliff dwellings” of Mesa Verde were discovered by the Wetherill Brothers, Richard, Win, Clayton, Al and John, and their brother-in-law Charlie Mason. It was the Wetherill Family who made the sites public and began the first archaeological tours of the area. As the popularity of the area grew, so did danger to the sites from looters and vandals. This increasing threat was the impetus for the designation of the park in 1906 as a

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12 Ibid. Pg. 25.
13 Ibid. Pg. 27.
protected area. Excavation and stabilization of the largest alcove sites began shortly thereafter, in 1908\textsuperscript{14} and seventy years later it was designated as the first UNESCO World Heritage Site in the United States.\textsuperscript{15}

2.1.2 Geology

The Mesa Verde Plateau rises approximately 2000 feet from its surrounding countryside.\textsuperscript{16} It is composed of marine sediments deposited during the Upper Cretaceous period,\textsuperscript{17} making them between 78 and 91 million years old.\textsuperscript{18} The four layers that make up the primary geology of Mesa Verde are the Mancos Formation, Point Lookout Formation, Menefee Formation and Cliff House Formation (figure 2.1).\textsuperscript{19}

The approximately 2000 foot thick Mancos Formation is composed mainly of shale and limestone beds,\textsuperscript{20} while the overlying Point Lookout Formation, only 30 to 40 feet thick, is of a much harder sandstone.\textsuperscript{21} The Menefee Formation is composed of irregularly alternating beds of soft shale, coal and sandstone. Finally, the Cliff House Formation, in which all of the alcove dwellings in the park are built, composes the uppermost rock layer in the park.\textsuperscript{22} It consists of two massive, cliff-forming sandstone

\textsuperscript{19} Ibid. Pg. 11.
\textsuperscript{20} Ibid. Pg. 45.
\textsuperscript{21} Ibid. Pg. 53.
\textsuperscript{22} Ibid. Pg. 59.
beds separated by thin beds of shale. This combination of sandstone and shale is what allows for the formation of the numerous alcoves in the canyons of Mesa Verde.

![Figure 2.1 Geological section of Mesa Verde National Park showing formation placement. Adapted from Guide to Mesa Verde National Park by Mary O. Griffitts. Pg. 11.]

2.1.3 Climate

Mesa Verde is located in a cold, middle latitude, semiarid climate. It receives an average of 18 inches of precipitation annually, although this number varies widely from year to year, with a range between at 10 and 30 inches. Most of this precipitation falls in the form of snow during the months of January and February, and as regular afternoon

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23 Ibid. Pg. 59.
thunderstorms in July and August.\textsuperscript{26} The regular seasonal cycle of relative humidity shows an average high of approximately 60\% in the month of January, which gradually decreases to an average low of approximately 25\% in the month of June. From June to December, relative humidity increases gradually until reaching an average high of approximately 75\% in December.\textsuperscript{27} Despite this general pattern, daily relative humidity fluctuates widely, and can range anywhere from 5\% to 95\% during any time of the year.\textsuperscript{28}

\textbf{2.2 Spruce Tree House}

\textbf{2.2.1 Location And Site Description}

Spruce Tree House alcove site is situated on Chapin Mesa, in the eastern side of Spruce Tree Canyon towards the south boundary of the park (figure 2.2).\textsuperscript{29} The crescent-shaped alcove measures approximately 216 feet and its greatest width, while at its greatest depth it is approximately 89 feet.\textsuperscript{30} The alcove is oriented lengthwise from north to south and faces west into the canyon. Spruce Tree House contains about 130 rooms and 8 full kivas.\textsuperscript{31} Archaeological research suggests the dwelling was home to between 60 and 80 Ancestral Puebloans after its construction in A.D. 1211. The site was

\textsuperscript{28} Ibid. Pg. 154.
\textsuperscript{31} Ibid.
abandoned by A.D. 1278. Spruce Tree House was first discovered by white settlers in 1888 and was opened to the public following its excavation and stabilization in 1908.

2.2.2 Alcove Formation

Spruce Tree House alcove was formed in a similar fashion to most of the other alcoves in which dwellings are located in Mesa Verde National Park, such as Cliff Palace and Balcony House. These alcoves are located in the Cliff House formation, which consists of massive sandstone beds separated by thin layers of shale. The sandstone generally has high porosity and permeability, allowing groundwater to percolate easily

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32 Ibid.
33 Ibid.
through it.\textsuperscript{35} When the water reaches the boundary between the permeable sandstone and the relatively impermeable shale layer, it proceeds to move laterally along the upper surface of the shale bed.\textsuperscript{36} When the water reaches the edge of a canyon, such as Spruce Tree Canyon, it seeps out of the sandstone above the shale layer. The water moving within the stone gradually weakens the bond between the loosely cemented sandstone grains both chemically through the production of weak carbonic acid and mechanically, through erosion.\textsuperscript{37} The water steadily erodes a niche in the sandstone just above the shale layer. As water continues to collect in the area, freeze/thaw cycling, salt crystallization and further erosion cause the niche to widen and large sandstone boulders to dislodge from the upper boundary of the opening, forming a large cavern.\textsuperscript{38}

\textit{2.2.3 Definitions}

For the purposes of this thesis, the following definitions apply (figure 2.3):

- **Alcove Opening**- The negative space within the canyon wall that houses the architecture of the site.
- **Alcove Ceiling**- The upper boundary of the alcove space.
- **Rear Alcove Wall**- The boundary formed by the eastern wall of the alcove that slopes downward towards the alcove floor. While it is a continuation of the alcove ceiling, here it will refer only to those portions of the wall against which architecture is built.
- **Upper Canyon Wall**- The relatively vertical portion of sandstone that forms the wall of Spruce Tree Canyon above Spruce Tree House alcove.
- **Lower Canyon Wall**- The steep talus slope leading from the lower boundary of Spruce Tree House alcove to the floor of Spruce Tree Canyon.
- **Roof Line**- The point of transition between the vertical Upper Canyon Wall and the sloped Alcove Ceiling that marks the
boundary between the volume of the canyon and the volume of the alcove.

- **Room**-Any above-grade space within the alcove that is bounded by at least two full or partial freestanding walls.
- **Freestanding Wall**-Any above-grade vertical wall with open space on either side.
- **Kiva**-A round subterranean room of specific construction used for ritual purposes.
- **Kiva Retaining Wall**-Any curved wall of a kiva with the concave surface unsupported and the convex surface subject to load from backfilled soil.
- **Open Area**-A space that is defined by the exterior walls of surrounding structures, natural features such as boulders, retaining walls, or some combination of the three.39

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Figure 2.3 Basic section of an alcove dwelling showing definitions used in this thesis. This drawing not to scale.
2.2.4 Wall Construction

The freestanding walls of Spruce Tree House are constructed for the most part of dressed sandstone blocks laid in earthen mortar (figure 2.4). The joints often contain small stones or fragments of pottery to serve as chinking material, which helps protect the mortar joints from cracking and shrinking.\(^{40}\) The majority of the walls at Spruce Tree House are one stone width thick, and room corners are rarely tied together with masonry units.\(^{41}\) Some remaining walls are as many as three stories high, while others have collapsed to just a few courses. Rectangular and T-shaped doors provide entry to most rooms, and some rooms retain remnants of their timber and plaster ceiling structures. Many of the freestanding walls are covered with decorative plaster, including some with embellishments. There are also walls that show no evidence of previous plaster decoration; there does not seem to be a pattern regarding plastered versus non-plastered walls.

2.2.5 Kiva Construction

The kivas of Spruce Tree House, and in fact at most ancestral Puebloan sites, are either circular or keyhole-shaped and have specific construction traits and features.\(^{42}\) They are subterranean rooms with an average depth of approximately 8 to 10 feet. Most of the kivas in Spruce Tree House were excavated by the ancestral Puebloans into the rubble floor of the alcove, or fill was added around the spaces to make them appear

\(^{41}\) Ibid. Pg. 10.
subterranean. The walls of the kivas were formed by coursed masonry units laid in earthen mortar and backed by rubble or soil fill.\textsuperscript{43} The floors of the kivas in Spruce Tree House were either covered with an adobe finish on top of soil fill, or were excavated several inches into the bedrock of the alcove floor.\textsuperscript{44}

A typical kiva has several characteristic features; these include

- **Banquette**- A low bench that surrounds the perimeter of the kiva and protrudes approximately 1 to 2 feet from the kiva wall.
- **Pilasters**- Rectilinear pillars built up from the top of the banquette surface to the floor level above the kiva. Pilasters would have supported a cribbed timber roof, which would have been covered over with plaster, forming an open courtyard.
- **Hearth**- a depression in the floor near the center of the kiva where fires would have been built.
- **Ventilator shaft**- A narrow L-shaped tunnel leading from the floor level at the roof level of the kiva to an opening at the base of the inner kiva wall. The function of this opening was to bring fresh air into the kiva while flushing out smoke and debris from the fire in the hearth.
- **Deflector wall**- a small partial wall made from masonry units or of a single stone slab that is placed between the opening of the ventilator shaft within the kiva and the hearth for the purpose of diverting air flow around the fire.
- **Sipapu**- a small hole approximately 8 inches deep cut into the floor of a kiva that symbolizes the place of emergence of the underworld.\textsuperscript{45}
- **Niche**- one of possibly several spaces in the stone walls of the kiva potentially for the storage of ritual objects

These features can be seen in figure 2.5, which shows a typical kiva in section view.

For the most part, kivas are oriented with the deflector wall to the south, followed

\textsuperscript{44}Fewkes Book, *Mesa Verde Architecture*
to the north by the hearth and then the sipapu. In keyhole-shaped kivas, the keyhole niche is almost always at the south side of the structure.\textsuperscript{46} Entry to a kiva would have been through a hatch in the timber and plaster roof into which a ladder was placed. This hatch would also serve as a chimney, allowing smoke and debris from the fire to escape the enclosed space and be replaced by fresh air from the ventilator shaft. Kivas almost always have plastered interiors, often including complex embellishments and several layers showing constant care and maintenance by their users. Spruce Tree House has 8 full kivas, (figure 2.6) one of which, Kiva B, has been backfilled to protect it from visitor and environmental impacts. It is located towards the north end of the site under the modern visitor path and was not sheltered by the alcove ceiling.

\textsuperscript{46} Ibid. Pg. 51.
Figure 2.4. Types of walls found in Mesa Verde National Park. Walls in Spruce Tree House are mostly of the Single Stone Wide type and are wet-laid or dry-laid mud. Image from Dirt, Water, Stone: A Century of Preserving Mesa Verde by Kathleen Fiero

Figure 2.5 Typical kiva in section view. The drawing not to scale.
Figure 2.6 Plan view of Spruce Tree House with kivas highlighted in blue. Plan drawing courtesy of National Park Service.
2.2.6 Stabilization History

Spruce Tree House was the first alcove site excavated by Dr. Jesse Walter Fewkes, of the Bureau of American Ethnology, under contract to the Department of the Interior. As such, it has a long and varied stabilization history. Upon excavation of the site in 1908, Fewkes made the following remarks regarding its stabilization:

‘Archaeological experts may differ in their judgments regarding the extent of work necessary to repair a ruin as much mutilated as Spruce Tree House. It is difficult to determine a strict line of demarcation between repair and restoration work...[the author] has endeavored to preserve the picturesque character of the walls when possible and has not attempted to foist on the observer any theory of construction that was not clearly evident.”47

Here Fewkes has set forth his stabilization philosophy, which informed his treatment of Spruce Tree House and the numerous other sites he excavated at Mesa Verde. Unfortunately, documentation of his work at the site is scarce. However, we do know that he used the same materials in his repairs as were used by the original builders of the site, including mud mortars and earthen plaster finishes.48 Work at Spruce Tree House involved the excavation and stabilization of the wall enclosing the front (west side) of the site, which Fewkes rebuilt to less than half of its original height so that views of the architecture would be uninterrupted from across Spruce Tree Canyon.49

Other changes Fewkes made to the architecture of the site were to partially reconstruct freestanding walls with original stones and to construct roofs over two of the

47 Ibid. Pg. 27.
48 Ibid. Pg. 74.
49 Ibid. Pg. 73.
kivas.\textsuperscript{50} He also completely stabilized Kiva G, restoring the upper portions of its collapsed walls and rebuilding or restoring 75\% of the pilasters in the space.\textsuperscript{51} After stabilization of this kiva was complete, Fewkes covered the entire interior with a layer of plaster of varying thickness, including portions that still contained original plaster.\textsuperscript{52}

At the time of his stabilization in 1908-09, Fewkes made note of the fact that water cascading over the mesa top and into the alcove was the single most destructive natural force affecting the architecture of Spruce Tree House.\textsuperscript{53} He dealt with the issue by cutting a 254-foot long, 2-foot deep and 3-foot wide trench into the stone of the mesa top above site in order to divert surface water to either end of the alcove where it would not affect cultural remains.\textsuperscript{54} The efficacy of this water diversion trench has not yet been studied.

The exact parts of Spruce Tree House stabilized by Jesse Walter Fewkes are unknown due to a lack of documentation. His stabilization program continued until 1922, when he left the park. His position was filled by Superintendent Jesse Nussbaum, who focused much of the park’s funding on infrastructure improvement and visitor services. Towards the end of Nussbaum’s years as superintendent, the Great Depression had swept

\textsuperscript{50} Ibid. Pg. 75
\textsuperscript{52} Ibid. Pg. 273.
\textsuperscript{54} Ibid. Pg. 75.
the country and severely decreased the amount of funding available to National Parks.\textsuperscript{55}

In 1934, James A. Lancaster was hired at the park to assist in a “Ruins Stabilization and Repair Program” that was funded in part by Franklin Delano Roosevelt’s New Deal.\textsuperscript{56} Lancaster was at the park until 1964, during which time much of his work dealt with the stabilization of Spruce Tree House alcove itself, which had suffered a number of rock falls since the 1920s and was continuing to develop visible faults.\textsuperscript{57} In 1940 Lancaster noticed two cracks in the sandstone above Spruce Tree House bounding a nearly detached slab of stone. Under Lancaster’s direction, the cracks were filled with asphalt and covered to keep out rain and snow. Vegetation in the area was also cleared to prevent root growth from exerting further pressure on the unstable stone.\textsuperscript{58} The cracks were resealed and refilled throughout the 1950s.\textsuperscript{59}

A major rock fall in 1960 led to the decision to actively remove loose stone fragments from the upper canyon wall and to continue securing large detaching sandstone slabs with bolts and grout.\textsuperscript{60} In 1961, a copper lip was installed to divert water away from areas where former rock falls had occurred and from the sealed cracks in the upper canyon wall.\textsuperscript{61} The alcove has remained relatively stable since the 1960s, although changes affecting the water flow above and around the site have continued. A noticeable change was the addition of a scupper to the drainage ditch created by Fewkes in 1909 by

\textsuperscript{55} Ibid. Pg. 32.  
\textsuperscript{56} Ibid. Pg. 33.  
\textsuperscript{57} Ibid. Pg. 75.  
\textsuperscript{58} Ibid. Pg. 75.  
\textsuperscript{59} Ibid. Pg. 75.  
\textsuperscript{60} Ibid. Pg. 77.  
\textsuperscript{61} Ibid. Pg. 77.
stabilization manager Kathleen Fiero in 1997. 62 Another scupper was installed at the same time at the south end of the site, although it is far less visible. 63 These scuppers serve the purpose of projecting water falling over the mesa top farther into the canyon, where it avoids coming in contact with retaining walls at the front of the site or archaeological deposits directly underneath the alcove opening.

The architecture within Spruce Tree House is for the most part more stable than architecture in other alcoves at the park due to the fact that it is a dry cave with no seep spring to introduce water directly into the site. 64 Despite its apparent stability, it has been subjected to several repair campaigns since its excavation in 1908. Documentation of these campaigns is sparse, and no monitoring was ever put into place to test their effectiveness. More recent repairs to Spruce Tree House have included the hardening of the alcove floor with Portland cement and amended earthen materials in selected areas and the installation of silicone drip edges to divert water from entering the alcove. A map of these more recent interventions is not currently available. Again, the efficacy of these measures has never been measured, and in some cases, they seem to have worsened the extant conditions. For example, areas of hardened floor do not absorb water and instead channel it towards more vulnerable areas of the site.

A monitoring program at Spruce Tree House would not only confirm the likely causes of deterioration at the site, but would also be available to test the efficacy of any future interventions. This will be integral in developing a comprehensive maintenance

62 Ibid. Pg. 77.
63 Ibid. Pg. 78.
64 Ibid. Pg. 75.
plan that allocates resources in the most efficient way possible. More research should be done to develop a specific timeline of past interventions in order to inform future management of the site.
CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

The conservation and management of standing architecture at excavated archaeological sites in the United States has for the most part taken the form of reactive stabilization or emergency mitigation. Such methods are not cost effective, as they do not address the source of the deterioration, only the symptoms caused by it. As such, degradation continues to occur by the same means. In addition, mitigation procedures often result in the loss of historic fabric, as they are only used in the event that part of a site is in danger of destruction or has already been destroyed. Such is the case at Spruce Tree House. While certain preventive measures have been taken in the form of installations of silicone drip edges and small channels created to control the flow of water within the site, these measures have had little effect on the greater patterns of deterioration there, as evidenced by the continued degradation of both plaster and stone.

This thesis presents a method by which a preventative maintenance plan for Spruce Tree House can be effectively developed and carried out by the National Park Service and its employees. The process includes an in-depth look at the necessary and sufficient factors causing active deterioration at the site and an organized system for monitoring its conditions and environment. The history of the site’s stabilization and past deterioration must be understood, as well as the natural and uncontrollable deterioration mechanisms caused by the alcove structure, formation and continuing evolution. Overall, it is a complicated process that requires consistent observation of the site and careful analysis of its dynamic environment.
Much research regarding environmental monitoring can be found in the realm of environmental and ecology studies as well as in the field of architectural conservation. This type of research can deal with monitoring as it applies to climate change and its effects on wildlife populations and air and water quality. However, it can also deal specifically with the monitoring of the environment at historic or archaeological sites. Examples found deal with both environmental monitoring and site management.

Site management research with respect to archaeological sites has for the most part dealt with excavation and interpretation. Preservation research that addresses site management often explains specific case studies in which remedial emergency conservation was undertaken. Although this research deals with the causes of deterioration, it often stops well before larger issues are taken into account, such as how future deterioration may be prevented or how previous management of the site may have contributed to deterioration mechanisms.

Those case studies which address both environmental monitoring systems and site management most often deal with temperature and humidity control inside historic buildings or inside museums that house historic collections. However, monitoring and site management case studies dealing with outdoor archaeological sites do exist, although these deal mostly with cave sites that house rock art paintings or carvings, as opposed to those sites which contain standing architecture.65 Thorough case studies of this type

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include the study done at the caves of Lascaux\textsuperscript{66} and studies of the Mogao Grottoes in China.\textsuperscript{67}

The following literature review considers research performed on the process and advantages of environmental monitoring as well as several case studies of successful monitoring programs that have been implemented at a variety of sites. Although not all of the research presented here was produced with the goal of archaeological site conservation in mind, it can be used to address this very specific problem. This review is by no means a complete list of existing research on these topics. However, what is presented here provides the framework for the research that remains to be done in order to develop a complete plan for the environmental monitoring of Spruce Tree House alcove and for its future maintenance and protection.

\subsection*{3.2 Environmental Monitoring}

Monitoring systems can be implemented for the purposes of observing, explaining or controlling.\textsuperscript{68} In the case of Spruce Tree House, a monitoring system will need to be put into place to observe the surrounding environment, and to explain its effects on the site’s deterioration. This system might also be used to monitor the rate of deterioration, thereby determining a mechanism’s severity and whether or not it is past or active. Long-


consistent surveillance is integral to distinguishing between change that is short-term and cyclical and change which may be part of a long-term, possibly irreversible trend. Literature on monitoring programs for the natural environment recognizes that change is a natural and unavoidable process for any system. It also acknowledges the need for the ability to detect undesirable change, knowledge of appropriate methods for halting or even reversing it, and means whereby the efficacy of the remedial action can be measured.

Although this research was done with respect to monitoring natural environments in order to measure change and quality, it is easy to see how it could be applied to historic structures or archaeological sites.

The process for developing a monitoring program for archaeological sites can also be similar to that for wildlife and ecosystem management. According to an article in the Journal for Wildlife Management,

To be effective…monitoring programs should (1) be framed by well-articulated objectives that are closely linked to management goals; (2) measure a subset of informative indicators with sampling methods that permit unbiased and statistically powerful results while minimizing costs and logistical problems; (3) ensure program continuity despite the vagaries of change in personnel, technology, and program objectives; and (4) quickly make accessible appropriately analyzed information to a wide audience,

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70 Ibid. Pg. 31.
particularly policymakers.\textsuperscript{71}

The same article states that “the goal of monitoring is generally to develop a scientifically defensible estimation of the status and trends in…resources and to determine whether management practices are sustaining those resources or should be changed.”\textsuperscript{72} These requirements would be the same for a monitoring program installed in any historic structure or archaeological site.

It is also important to take into consideration the issue of cost effectiveness when designing a monitoring program. The purpose of such a program is often to prioritize areas for treatment depending on available financial resources. Along the same lines, it is important to know when parts of a site are too deteriorated to benefit from a repair program.\textsuperscript{73} These areas should be stabilized for safety reasons and should be incorporated into the site interpretation in a way that is not dependent upon archaeological authenticity.

3.3 Monitoring at Cultural Heritage Sites

The ultimate goal of archaeological site monitoring is the successful management and interpretation of historic resources. A great deal of research has been done on the most effective means of site management, but much of this has omitted the idea of environmental surveillance as a way to develop maintenance and preservation plans.


\textsuperscript{72} Ibid. pg. 1056.

Studies that have been done on the development of monitoring systems for historic sites can provide valuable insights into the most effective methods for developing such a program at Spruce Tree House.

A good deal of previous research in the field of monitoring for historic sites has focused the internal environments of museums housing historic collections. Early studies developed in the 1970s with the advent of automated Heating Ventilation and Air Conditioning (HVAC) systems, with which internal environments could be more closely controlled. It was also in the early 1970s that environmental monitoring came to be viewed as an important tool for measuring the effects of excavation on long-buried archaeological sites. One early example of an environmental monitoring system applied to an open-air archaeological site is the case of Tumacacori National Monument, an adobe mission church in Southern Arizona built in the late 18th and early 19th centuries. The National Park Service began a preservation initiative there in 1976 that concentrated on the causes of decay by “analyzing the characteristics of the adobe building material and the conditions in the microenvironment which were thought to have an effect on the material.” At that time, the site was badly in need of stabilization and preservation treatments, but the managers of the project knew it was not feasible to begin such work.

without thorough knowledge of the conditions that led to the most prevalent forms of deterioration.\textsuperscript{78} The first step in the preservation process was therefore to develop “a well designed system to gather pertinent information.”\textsuperscript{79} According to Anthony Crosby, an historic architect working for the National Park Service at the time who was involved with the Tumacacori monitoring project,

The primary purpose of this monitoring system [was] to record various conditions in the structures and in the microenvironment so that those conditions which actually cause deterioration [could] be identified. After this identification, specific repair based on the actual causes of significant deterioration [could] be undertaken.\textsuperscript{80}

Monitoring at Tumacacori continued for over a decade and included measurements such as temperature, wind speed, relative humidity, precipitation and solar radiation at the site, as well as sub-surface moisture conditions. Diagnostic tools used included simple psychrometers, visual observations and material sampling as well as more complex moisture sensors, crack propagation gauges and conductivity meters.\textsuperscript{81} The carefully designed program led to a deeper understanding of the cause and effect relationships linked to deterioration at the site and allowed its stewards to develop a sensitive and proactive maintenance plan for its protection.

In 1984, the scientific program of the Getty Conservation Institute started an environmental research program based on the protection and conservation of cultural

\textsuperscript{79} Ibid. Pg 51.
\textsuperscript{80} Ibid. Pg. 53.
heritage. This was the first major research initiative to focus on the effects of the changing environment on heritage resources. While this program dealt mainly with microenvironments in museum settings and the effects of air pollution on cultural property, it succeeded in bringing to the forefront the relationship between environment and the deterioration of valuable historic resources.

At around the same time, in 1985, research was being performed in the United Kingdom on the use of computerized monitoring systems for museum climate control. Before that time, museums had recognized the importance of climate control and monitoring of collections, but were doing most of the measurement manually. A paper presented at the 11th Annual Conference of the Canadian group of the International Institute for the Conservation of Historic and Artistic Works describes the design and installation of an automatic monitoring system for the museum housing artifacts recovered from the Mary Rose, an early 16th Century British ship. The author states that, while the system did encounter some initial problems, it proved useful for the management of the museum and assisted personnel in formulating preventive conservation measures for the collections. Computer technology has obviously advanced substantially since the 1985 Conference, but the general principles set forth there provided a basis for many monitoring systems in use today.

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84 Ibid. Pg. 299.
In the late 1980s and early 1990s, the conservation and stabilization of the Tomb of Nefertari, located in the Valley of the Queens near Thebes, Egypt, led not only to the protection of the wall paintings housed in the tomb, but also to the recognition that the microclimate and hydrological conditions of the tomb had to be understood and addressed in order to prevent further decay.\(^8\) A monitoring system, installed at the tomb in 1991 recorded the environment both inside and outside the tomb, in order to track the correlation of the internal conditions with the exterior environment.\(^6\) The project also addressed the impact of visitors on the site, measuring temperature, relative humidity and carbon dioxide at different times of day when different numbers of tourists had visited the tomb.\(^7\) This information was used to create reasonable limits on the number of visitors allowed at the site per day and on the duration of each visit.

The environmental monitoring of the Mogao Grottoes, located 1800 kilometers west of Beijing along the Silk Road in Northwestern China also began in 1991 in response to increasing visitation and concern about its potential effects on the cultural resources of the Grottoes. These caves represent one of the most important and complete collections of Chinese Buddhist mural art in the world, and despite their remote location, they have been subject to increasing threats from tourist visitation.\(^8\) The monitoring program created in response to these threats recognized that basic facts about the

environment and the stressors affecting the site would need to be obtained before any remedial conservation work or stabilization measures could take place. The system included a solar-powered meteorological station located on the cliff face above the caves as well as substations measuring temperature, relative humidity, carbon dioxide and number of visitors inside both open caves and caves closed to the public. In this manner, information from visited caves could be compared to that from closed caves and the relative levels of deterioration in each type could be related to environmental factors. The monitoring scheme was operated for a minimum of four years and local staff members were trained in data collection and maintenance of the equipment. Results allowed the stewards of the site to implement climate control measures in caves visited by tourists and therefore contributed to their prolonged preservation.

Yet another cave site with important prehistoric art that underwent a monitoring regimen in the early 1990s was the Cueva de Altamira, located near the town of Santillana del Mar, on the northern coast of Spain. Although research on the microenvironment there began in the early 1980s, data collection and analysis was

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92 Ibid.
sporadic and by 1990 the existing equipment in the cave had ceased to function.\textsuperscript{93} A new monitoring campaign was designed in 1993 specifically for the site and the unique challenges it presented:

The complexity of the conservation of a natural ecosystem like the Cueva de Altamira made it necessary to collect a large quantity of data on a variety of factors, many of which required continuous and simultaneous monitoring. The acquisition of these data required, also, an assembly of different kinds of sensors and devices, either standard or adapted, selected from the choices offered by current technology.\textsuperscript{94}

In addition to choosing the most appropriate tools for the measurements to be taken, the project leaders also made sure that the overall system allowed for expansion with the evolution of monitoring technologies, was easy to use and could be managed and maintained by the local site managers, had the capacity for operation from a remote location and was accessible for repairs and reversible, so as not to cause permanent damage to the natural or cultural resources of the cave.\textsuperscript{95} Although this represents a relatively early comprehensive monitoring program for an archaeological site, the process by which it was designed is instructive and can be applied to current design problems.

In the US in the early 1990s, the Image Permanence Institute (IPI) at Rochester Institute of Technology in Rochester, NY became interested in environmental approaches to preservation management, especially in a museum setting. As part of its research, the

\textsuperscript{94} Ibid. Pg. 82.
\textsuperscript{95} Ibid. Pg. 82.
IPI developed tools and approaches specifically for use in cultural institutions, such as hardware for data gathering, software for data analysis and reporting and a service through which IPI could be contracted to perform a one time, short-term environmental monitoring and analysis program.96 Part of the IPI’s monitoring philosophy is that “monitoring should lead to action, and actions can’t be conceived in ignorance of the outdoor climate and the nature of mechanical systems.”97 The IPI’s development of a monitoring system for use specifically in the field of cultural resource preservation highlights the significance this tool should have in any process leading to conservation interventions.

The late 1990s saw an increase in monitoring programs applied to archaeological sites in North America. One of these programs was instituted at Mesa Verde National Park, at Mug House, an alcove site no longer open to the public. The alcove in which Mug House was built was formed much as Spruce Tree House alcove was, although it is slightly smaller. The architecture of the site comprises 90 rooms and eight kivas. Environmental monitoring at Mug House was part of a five-phase project begun in 1994 to document and treat the earthen surface finishes there.98 Monitoring in this case was not implemented prior to conservation treatments; rather, it was used to evaluate the efficacy of those treatments and of certain temporary protection systems installed at the site to

97 Ibid. Pg. 9.
shelter its decorative earthen finishes.99

Another in-depth study of environmental monitoring for the purpose of conservation planning was undertaken at Drayton Hall in Charleston, South Carolina in the late 1990s. The monitoring system designed by the team of researchers on that project was meant to test predetermined hypotheses about the causes of deterioration on both the interior and exterior of the house.100 Their hypotheses led to a number of monitoring components including temperature and humidity sensors, crack monitors, strain gauges, water sensors and contact switches.101 Data was collected by these devices over a 12-month cycle. Using this data and climate data for the area, the research team was then able to make a set of recommendations to the National Trust for Historic Preservation, the steward of Drayton Hall, for the future management of the site with the aim of slowing or stopping active deterioration mechanisms.102 Because there is no active climate control system in the house, recommendations included a set of practical procedures that could be implemented by the staff to reduce stress on historic materials caused by environmental factors.103 Obviously the climate inside Spruce Tree House alcove cannot be controlled by mechanical means. The study at Drayton hall therefore gives an example of simple measures that can be taken to manipulate an environment without the installation of costly equipment.

Another component of the monitoring strategies developing in the late 1990s and

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99 Ibid. Pg 32.
101 Ibid. Pg. 65
102 Ibid. pg. 70.
103 Ibid. Pg. 68.
early 2000s was their incorporation into the general management plans of many historic sites. During these years site managers began to see the benefit, and in some cases necessity, of monitoring before making any major changes to the management and preservation of a site. It was during these years that monitoring began as a proactive measure, as opposed to a reactive measure. While it still almost always occurs as a response to observed deterioration, monitoring is currently seen as the first step in any preventive maintenance plan, helping conservators and site managers avoid drastic losses.

In the late 1990s, a monitoring program was initiated at a mosaic site on the Isle of Wight in England. Brading Roman Villa is a 4th century site that contains an impressive collection of ancient mosaics.\textsuperscript{104} This program is notable for its recognition that detrimental environmental conditions need to be rectified and controlled before conservation work can begin and also for its consideration of the mosaics as part of the larger context of their natural and built environments.\textsuperscript{105} The monitoring program helped conservators develop a minimally invasive conservation plan including the creation of a more stable environment for the artifacts.

In 1999, an integrated monitoring program was initiated at a similar site, Chedworth Roman Villa in Gloucestershire, England. Also built in the 4th century, Chedworth was discovered in 1861 and has been progressively excavated since that time.


\textsuperscript{105} Ibid. Pg. 102.
It contains some of the best *in situ* ancient mosaics in Britain as well as extant original decorative plaster finishes.\textsuperscript{106} Multiple variables were measured at the villa for over three years, including air temperature, surface temperature, relative humidity, precipitation and soil moisture content.\textsuperscript{107} The importance of measuring and relating a variety of environmental factors at the site is explained here:

The monitoring of multiple parameters simultaneously on a unitary system enables an integrated approach to the diagnosis of mechanisms of deterioration by identifying specific relationships between environmental factors and their interdependency.\textsuperscript{108}

A useful component of this study is the discussion of challenges associated with the monitoring system that was put into place at Chedworth. These included the long amount of time necessary to collect data, the loss of data due to rodent interference with the equipment, and in some cases choosing sensors that were inappropriate for the conditions in which they were placed.\textsuperscript{109} This discussion underscores the importance of taking into account all possible conditions at a site before installing monitoring equipment in order to avoid costly repair or replacement measures.

A final study that can be used as an example of a successful design for a monitoring program is that installed at Mawson’s Huts, a group of four historic huts associated with the 1911-1914 Australian Antarctic Expedition. They are located at Cape

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\textsuperscript{107} Ibid. Pg. 187.

\textsuperscript{108} Ibid. Pg. 183.

\textsuperscript{109} Ibid. Pg. 186.
Denison, Commonwealth Bay, Antarctica. As one might imagine, the huts are located in a particularly inhospitable environment, which not only poses a problem in terms of ice removal from the buildings, the main conservation issue, but also puts limitations on the number and type of monitoring sensors that can be used.110 Before monitoring was implemented at the site, the reasoning behind a monitoring regimen was thoroughly explained and justified in the Conservation Management Plan for the site:

Monitoring will be an essential tool in the management of Mawson’s Huts. It will aid understanding of the existing conditions of structures and environment in and around the huts to provide justification for proposed works, to assist in assessments of potential impacts of proposed works, and to review the effectiveness and impact of works once they are undertaken.111

Here, perhaps more than in any study discussed so far, was monitoring used in a proactive manner, not just as a responsive mechanism once decisions had already been made.112

Another interesting and unique aspect of this site was its use of monitoring as a decision-making tool for the site management. Results were often valuable in resolving conflicting issues between professionals with opposing viewpoints, as they offered solid evidence in the form of numbers and mechanical measurements. This made the process more objective.113

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111 Ibid. Pg. 27.
112 Ibid. Pg 28.
113 Ibid. Pg. 31.
3.4 Conclusion

The sites discussed here prove that any monitoring program must be tailored to the needs of the site and to the specific research questions formulated by site managers and conservators. Research that deals with monitoring open-air archaeological sites is still scarce. One reason for this is most likely the sheer size often presented by such sites. The manpower and financial resources needed to implement a useful monitoring system at any large outdoor site can be prohibitive. Often the only monitoring that can be accomplished is a general survey of conditions, which then leads to a prioritization of those parts of the site in most danger of destruction.\textsuperscript{114} However, after this survey is completed, the necessary follow-up steps are rarely taken to discover and address the most severe causes of deterioration or to monitor more consistently the characteristics of the site that might be contributing to its decay.\textsuperscript{115}

The research presented here is by no means a comprehensive description of all research that exists on environmental monitoring. Instead, this review provides an explanation of the areas of study that should be considered in the design and implementation of a monitoring and management plan for a unique archaeological site. The data found in the research presented here should be used to inform the development of an effective program that is nevertheless tailored to the individual needs and characteristics of Spruce Tree House alcove.


\textsuperscript{115} Ibid. Pg. 5.
CHAPTER 4: EXISTING CONDITIONS

There may be several mechanisms of active deterioration at Spruce Tree House. However, in the absence of prior and current conditions assessments, which would identify slow changes that have taken place over a long period of time, only the readily apparent, fast acting losses, and their possible causative mechanisms, can be targeted for measurement and monitoring at this point. Although a number of stabilization campaigns have taken place in the past few decades, many of these were not well documented and therefore do not provide a consistent record of past conditions at the site.

The most readily apparent condition is deterioration of the plasters that cover many of the walls of the site. The plaster is a decorative surface finish for these walls, but also protects the underlying stone and mortar from exterior conditions such as liquid moisture and wind. Where plaster loss is complete, losses in exposed stone and mortar can follow, which may, in turn, lead to structural instability. Therefore, it is important to reduce plaster loss due to its inherent decorative value but also for its long-term protective function for the underlying masonry structures.

This chapter will discuss in detail the readily apparent plaster, stone and mortar conditions observed during a brief site visit to Spruce Tree House in January 2009. Areas discussed are highlighted in figure 4.1. Stone and mortar losses may be the result of a number of different mechanisms. While such mechanisms may be related to the loss of plaster finishes, they cannot be conclusively attributed to a specific past or active cause without further investigation and analysis.
This chapter discusses the following aspects of the site:

- Plaster
- Salts
- Snow Drift
- Water Paths on the Alcove Ceiling

4.1 Plaster

The Architectural Conservation Laboratory at the University of Pennsylvania has made a distinction between what is termed ‘plaster’ and what is termed a ‘wash’. This distinction is based on the width of individual layers applied sequentially to the surfaces of the site. For the purposes of this thesis, the term ‘plaster’ refers to any intact earthen finish, in that it functions as both aesthetic expression and as a functional architectural component. Because the depth of the alcove at Spruce Tree House shelters a large proportion of the constructed fabric from rain, sun and wind, much of the extant plaster remains in excellent condition, especially considering its age and the fragility of the medium. This is a testament to the skill and knowledge of the inhabitants of Spruce Tree House regarding plaster formulation and application. However there are several unprotected areas of the site in which the deterioration of the plaster is being accelerated due to both external and internal factors. The following plaster conditions are currently represented at Spruce Tree House:

- Runneling
- Soil wash
- Total loss
- Salt efflorescence

Figure 4.1 Plan view of Spruce Tree House alcove with areas discussed in this chapter highlighted. Base map courtesy of National Park Service.
4.1.1 Runneling

Runneling is defined as rivulets or channels in the extant plaster at Spruce Tree House that extend downwards from the upper edges of freestanding walls and from the perimeters of uncovered kivas. It is currently the most prevalent adverse plaster condition at the site. Runnel paths often follow patterns in the texture of the underlying masonry. Runneling occurs on several of the freestanding walls in Spruce Tree House as well as down the exposed interior faces of the retaining walls of many of the kivas. Several of these areas will be discussed here, working from the above-ground rooms at the north end of the site to those at the south end, and then addressing several of the kivas.

Some of the most severe runnels appear at the northernmost tip of the alcove site, on the walls of the combined spaces labeled Open Area A and Open Area 1 (figure 4.2). These areas are open to the east, while the northeast wall of the space is formed by the rear wall of the alcove. The architecture in this area is less sheltered than that in the rest of the alcove. Structures here are directly below the roof line of the alcove ceiling. As a result, the interiors and exteriors of the freestanding walls of the structures are exposed to weather. Dramatic evidence of runneling is visible along both extant masonry walls of Open Areas A and 1. While there is evidence that the walls were once plastered, the plaster is no longer extant on much of the wall surface, with the exception of a few isolated patches. The plaster losses extend from the upper edges of the freestanding walls to approximately 7 feet above the floor of the alcove.

Damage in Open Areas A and 1 is particularly troubling for several reasons. The first is that the space houses the remains of an original wooden ceiling structure, with many of the primary beams, or *vigas*, and secondary beams still in place. In many instances the runnels and soil washes intersect with the timber embedment in the wall masonry and flow around the wooden members. Further deterioration of the plaster may lead to destabilization of the wood ceiling structure, as water continues to follow runnel paths and collect in the embedment spaces, potentially dislodging the timbers.

The curved southern freestanding wall of Open Areas A and 1 supports one of only four masonry columns in Mesa Verde National Park (figure 4.2). The feature was significant enough for Walter Jesse Fewkes to take note of it in his report on Spruce Tree House for the Bureau of American Antiquities, stating

This room possesses a feature which is unique. The base of its south wall is supported by curved timbers, whose ends rest on walls, while the middle is supported by a pillar of masonry.\(^{118}\)

Although it was stabilized in 2000, the pillar remains a valuable and fragile feature that may potentially be endangered by further damage. If runneling continues to affect the surrounding area, the plaster, and eventually the mortar, may weaken, causing the column to collapse.

A third reason to be concerned about Open Areas A and 1 is that they have obviously suffered damage since their last major stabilization campaign in 2000. There

are runnels on surfaces that were previously repaired, suggesting that while stabilization may have corrected the symptoms of the deterioration, it did not address its underlying causes. The deterioration mechanisms in this area of Spruce Tree House persist and, if allowed to continue unabated, have the potential to cause major structural as well as aesthetic damage.

The exterior freestanding walls of these spaces are also heavily damaged, along with the exterior walls of Rooms 2 and 3, which are adjacent to Open Areas A and 1 and lie to the south (figure 4.4). These walls lie beyond the roof line of the alcove opening and are therefore exposed to all weather conditions that exist throughout the year.

Figure 4.2 Visible runneling on the east face of the west wall of Open Area 1.
Figure 4.3 Curved timbers and masonry pillar located above Open Area 1.

Figure 4.4 Severe runnels on the upper portions of the exterior walls of Rooms 2 and 3.
Rooms 27 and 28, to the south of Open Areas A and 1 also exhibit damage from runneling, notably on both faces of the partial freestanding wall between the two rooms, and, to a lesser extent, on the eastern face of the partial west freestanding wall of Room 27. Like the areas discussed in the previous paragraphs, these two rooms are located underneath the drip edge of the alcove and are not completely sheltered by the alcove ceiling.

A third area of Spruce Tree House that is suffering from extensive runneling damage is at the site’s southern end. It encompasses a number of rooms and open spaces, including Open Areas 35, 23 and 24, as well as rooms 68 and 69. Again, the structures in this area are exposed to climatic conditions due to their location at the periphery of the alcove, where the alcove roof line recedes to just above where the freestanding walls are positioned. However, the damage here does not always occur on the walls underneath the roof line, but also on walls that are located far within the alcove, where the ceiling slopes more steeply inwards.

Open Area 35 is the southernmost named space in the Spruce Tree House alcove. Like its counterpart at the north end of the site, it is not sheltered by the alcove ceiling, which recedes just north of where the walls of Open Area 35 stand. Runneling is evident in this area in the southern corner, most notably at the intersection of the south and east masonry walls.

Open Area 23, a triangular open space to the north and west of Open Area 35 shows runneling on the south face of its north wall. The opposite side of that same wall, which is the south wall of Room 68, also shows runneling, along with the east wall of
that room. A section of the west wall of Open Area 24, the section that is shared with the east wall of Room 68, also shows evidence of runnels, despite the fact that it is completely sheltered by the alcove ceiling and lies approximately 12 feet inside of the alcove roof line. The runneling is located on the surface of the wall that faces the rear of the alcove (figure 4.5).

Room 69, a circular space with low walls around its perimeter is another room at the southern end of the alcove that exhibits runnels. This room is lies partially underneath the alcove roof line and is therefore not completely sheltered by the alcove ceiling. Runnels are most visible on its south and west walls.

Figure 4.5 Detail of runneling on the east face of the west wall of Open Area 24. This wall surface faces the interior of the alcove and lies well within the alcove space.
The retaining walls of the exposed kivas at Spruce Tree House are just as vulnerable, if not more so, to the deleterious effects of runnels as the walls of the above-grade room blocks. Three of the excavated kivas show serious damage as a result of these processes: Kivas E, G and H.

Kiva E is approximately equidistant from the north and south ends of the alcove and is towards the west, or front opening of the alcove. The north retaining wall of the kiva exhibits runnels just underneath a seam in the alcove floor at what would have been the kiva’s roof level, between an area of hardened and stabilized ground and an area of original plaster flooring (figure 4.6). This seam coincides with a vertical joint between two of the stones at the rim of the kiva. The runneling pattern appears to originate at this seam and spreads outward in all directions toward the pilaster directly below it. Once it reaches the pilaster the pattern continues to the west until it come to a stop at the horizontal surface of the banquette.

The most severe runnel-related damage in Kiva E is located on its west retaining wall, inside the keyhole niche above the ventilation shaft (4.7). At the south end of this niche there is a wide swath of bare masonry where the plaster is totally lost, likely due to this runneling. The paths of the runnels are highly visible and the deepest runnel appears to originate at a vertical mortar joint between two of the stones at the rim of the kiva. Beneath this joint, with the plaster no longer there to protect it, the mortar has begun to erode. This is the case from the top edge of the kiva down to the horizontal surface of the banquette above the ventilator shaft.
Figure 4.6 Seam in the alcove floor above Kiva E between stabilized floor and original plaster floor. Runnel descends from the seam to the banquette.

Figure 4.7 Severe runnels in the keyhole niche of Kiva E. Masonry and mortar substrate are visible in areas of plaster loss.
Kiva G provides an interesting study of deterioration at Spruce Tree House, as any damage that is now visible has occurred since the early 20th century, when Jesse Walter Fewkes stabilized, restored and re-plastered the entire unit. Although his plaster is not the same formulation as the original plasters remaining at the site, it is still an earthen-based finish, and therefore reacts to deterioration mechanisms in a similar manner as the plaster that has been on the walls of Spruce Tree House for nearly 800 years.\(^{119}\)

Numerous runnels of various widths occur in several places around the perimeter of Kiva G. In contrast with Kiva E, many of these runnels do not stop at the horizontal surface of the kiva banquette, but continue to affect the plaster on the lower portion of the kiva retaining walls until reaching the bedrock floor of the space. Two significant runnels are located on the upper portion of the west wall, above the ventilator shaft (figure 4.8). As in Kiva E, these runnels have completely removed a ribbon of plaster and appear to be eroding the mortar underneath. In the lower wall just to the north of the ventilator shaft, there is more evidence of runneling. The runnels in this area appear to originate from the corner of the niche just above the ventilator opening. There is evidence of mortar loss in addition to the loss of extant plaster.

Just to the south of these two runnels is a third, located above a pilaster. It is wide and appears to originate from an open vertical mortar joint between two of the stones at the kiva rim. Upon reaching the horizontal surface atop the pilaster, the runnel continues

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down its face to the kiva floor. There are two more significant runnels that correspond to total or partial loss of plaster in the south wall of Kiva G. These appear to extend beyond the banquette surface and continue down the lower portion of the kiva wall. Yet another runnel appears to the east of these two runnels; it originates at the juncture of the kiva rim and a low partial wall located at the kiva roof level just to the southeast of the space (figure 4.9). Several more runnels appear around the walls of Kiva G. Many of them reach from the kiva’s upper edge to its bedrock floor and spread horizontally outward as well as vertically downward. Some appear to be affecting the underlying mortar, which could eventually lead to stone displacement.

It should be noted that the floor above Kiva G has been stabilized and hardened with a cementitious material. It has a shallow slope towards the interior of the alcove and has necessitated the installation of a molded depression in the southwest corner of the open plaza surrounding the kiva. The hardened floor sheds water more easily than original flooring or soil, diverting it quickly into the alcove. The shallow molded trough in the flooring catches water and forces it to distribute more slowly throughout the space. All of this, as well as the deterioration described in the preceding paragraphs has occurred since approximately 1908, when Fewkes initiated his repair campaign of what he deemed the best preserved and most important kiva in the cliff dwelling.120

120 Ibid. Pg. 273.
Figure 4.8 Runnels in the keyhole niche of Kiva G, originating at a vertical mortar joint in the kiva rim. Masonry and mortar substrate are visible.
Figure 4.9 Runnel in the southeastern quarter of Kiva G that originates at the base of a low partial wall. Runnel appears to be directed by the wall and the adjoining boulder.
Kiva H suffers a great deal of damage in the form of runnels as well. The runnels in this space are wide and spread out, unlike the relatively straight and narrow runnels found in kivas E and G (figure 4.10). They cover the majority of the west wall of the kiva as well as areas in the north and south walls. In many cases they are leading to mortar loss and stone displacement. There appear to have been runnels in some places on the lower wall of the kiva, but as a good deal of plaster is already lost here, it is not possible to trace the location of past or present runnels.

Figure 4.10 Wide runnel at the north side of Kiva H. Masonry and mortar substrate are visible.
4.1.2 Soil Wash

While runnels are the result of a subtractive mode of deterioration, soil wash is the addition of earthen material to the masonry walls of Spruce Tree House or the plaster finishes that cover some of those walls. It appears as a thin coating of tan or brown soil on the vertical wall surfaces of both rooms and kivas at the site, as well as on the alcove ceiling itself. Soil wash can be deposited in one of two ways: it can be left on a surface by water that has carried it down that surface or it can be splashed onto a surface by water falling near the base of that surface. Both instances are observed at Spruce Tree House. Instances of the former type of soil wash deposition often occur in conjunction with observed runnels in plaster. There is not yet a definitive correlation between these two extant conditions; however the possibility that one exists cannot be ruled out. This will be discussed further in the following chapter.

Two representative areas of Spruce Tree House that exhibit soil wash are inside Kiva E and on the exterior partial wall that bounds the west side of Open Area 23. Soil wash in Kiva E is most apparent in the keyhole portion of the structure, adjacent to the ventilator shaft. In figure 4.11 it is visible as areas of darker material in a drip-like pattern on the west retaining wall of the kiva. The photograph also shows the proximity of the soil wash to runneling taking place in the plaster of the same area. In this case the soil wash appears to be a continuation of an incipient runnel forming at the upper edge of the kiva. This disintegrating plaster likely supplies the soil in the wash below.

The partial wall that contains Open Area 23 exhibits a different kind of soil wash pattern. In this case the wall, which has been stabilized in an attempt to protect it from
visitor disturbance, maintains a thin layer of soil at its base, which appears to have been splashed onto the surface from the ground just in front of it (figure 4.12).

A third area where soil wash is evident occurs not on the architecture, but on the sandstone of the alcove space. This is most obvious at the south end of the site, on the area of alcove ceiling above Open Area 35. Here the soil wash pattern appears as light tan material that has been deposited on the stone in thin lines running vertically down the stone surface (figure 4.13). This type of wash is similar to that seen in Kiva E, in that it appears to have been carried down the stone surface by running water.

Figure 4.11 Evidence of soil wash in the keyhold niche of Kiva E.
Figure 4.12 Soil wash on the partial wall that contains Open Area 23 on its western side. The thin layer of soil appears to have been splashed onto the wall from the ground.

Figure 4.13 Soil wash on the alcove ceiling above Open Area 35.
4.1.3 Total Loss of Plaster

Plaster damage also appears to occur in the form of wholesale loss of material. This type of loss takes place in relatively large areas over short periods of time, whereas plaster removal via runnels occurs at a slower rate. Wholesale plaster loss usually occurs in four stages: flaking, delamination, detachment and finally total loss.¹²¹

Flaking is defined as active surface failure of plaster finishes, while delamination is intralayer failure; that is, a separation between layers of plaster that have been applied sequentially over top of one another. Flaking and delamination can occur simultaneously and do not always occur in sequence. Furthermore, one need not occur in order for the other to begin. Although flaking usually begins first, as it affects an exposed surface of plaster, delamination has occurred in some instances while the surface layer of finish remains intact.¹²²

Detachment is another component in the process towards total loss of plaster finishes. It is defined as the loss of the bond between the bottommost plaster layer and its masonry substrate. Like flaking and delamination, detachment is not based on the occurrence of the aforementioned conditions and can take place even if the upper layers of plaster are intact. Detachment allows materials such as dust, dirt and moisture to accumulate between the finish material and the underlying masonry, making total failure

¹²² Ibid. Pg. 53.
and loss of the plaster more likely.\textsuperscript{123}

The final step in this process is the total loss of plaster from the masonry wall to which it was applied. Although soil wash and runnels can lead to the loss of plaster, for the purposes of this thesis, “total loss” will refer only to loss of plaster that appears to have taken place as a single event, as opposed to the gradual removal of plaster that often results from runneling. Areas of loss that occur by these two means of deterioration are different in appearance, and it can be inferred from careful observation by which mechanism the plaster has most likely been damaged.

Plaster loss by soil wash and runneling does not generally have a clear boundary between lost plaster and remaining plaster. Often, the edges of this type of area of loss are irregular and not easily distinguishable. In addition, plaster loss within these areas may only occur sporadically, and may be interspersed with plaster in various stages of decay. Areas of total loss as it has been defined for this thesis are discrete regions where plaster no longer exists. The edges of these regions are for the most part sharp and well defined.

Many of the surfaces at Spruce Tree House were never finished with plaster after their construction, and many of the once-finished walls now suffer from total plaster loss. Because there is no past conditions assessment with which to determine if this loss is recent, only total loss that appears to be directly related to an observable causative mechanism will be discussed here. These areas occur for the most part within the kivas, which were always plastered with decorative and protective finishes\textsuperscript{124}, and furthermore

\textsuperscript{123} Ibid. Pg. 53.
\textsuperscript{124} Ibid. Pg. 53.
appear to occur in the same pattern in each of the subterranean rooms discussed here.

In Kivas E, G and H, total plaster loss is evident around the entire perimeter of the kiva base, where the curved retaining walls meet the horizontal floor surface. The floor surfaces are made up of bedrock, puddled adobe or a combination of the two.\(^{125}\) In Kiva E, there is clear delineation of an area of plaster loss at the base of the lower wall. The upper walls of this kiva retain most of their plaster, as do the upper portions of the banquette walls. Kiva G also displays a clear pattern of plaster loss along the base of its lower walls (figure 4.14). As mentioned above, Kiva G was completely replastered circa 1908 by Jesse Walter Fewkes; any visible plaster loss has occurred since that time. This rules out processes related to site abandonment and excavation, as Fewkes restored the kiva well after these events. In addition to the visible loss at the bases of the kiva walls, there are also small discrete regions of plaster loss that occur on the upper walls of Kiva G and on some of the pilasters. This does not occur in the other kivas and may be due to the difference in composition of the Fewkes plaster.

Plaster loss in Kiva H is not as easily discernable as the loss in Kivas E and G. This is due mostly to the fact that there is less extant plaster in Kiva H and it is more difficult to delineate areas of loss from areas of past erosion (figure 4.15). However, as in the other two kivas there are discrete areas of loss that are evident along sections of the lower wall near the floor, especially below where there are large areas of extant plaster on the north and south sides of the kiva.

Figure 4.14 Total plaster loss at the base of Kiva G

Figure 4.15 Total plaster loss at the base of Kiva H.
4.2 Salts

Salt efflorescence is visible in many areas of Spruce Tree House, both on the shaped masonry blocks of the architecture and on the walls and ceiling of the alcove itself. Salts most likely originate within the sandstone, and are drawn to the surface by repeated and prolonged wetting, causing them to dissolve and eventually recrystallize. This process has been observed at other, similar sites in the park.\textsuperscript{126} There are two general areas at Spruce Tree House that show the most evidence of salt deposits: the south end of the alcove and the interiors of Kivas E, G and H (figures 4.16, 4.17, 4.18).

At the south end of the site, salts are visible on both upper and lower portions of the rear alcove wall above Open Areas 35 and 24, as well as at the back of Room 70. The salts that appear on the lower portion of the rear alcove wall are relatively uniform and blanket large areas of stone (figure 4.17). They are most prevalent under a ledge in the rock that houses several small masonry partitions. Sections of the stone beneath this ledge appear to be damp, although there was no apparent source of water, and other stone in the vicinity was dry. The salts that are visible on the upper alcove wall and ceiling appear to travel down the sandstone in a stream-like pattern, and occur in conjunction with the lines of soil wash previously discussed in this chapter (figure 4.18). The two distinct forms these salts take may indicate that they have been drawn from the sandstone by different sources of water. It is not known at this time whether the process of salt efflorescence is active or occurred in the past and has since halted.

Figure 4.17 Salt efflorescence on the rear alcove wall behind Room 70 and Open Area 24.
Figure 4.18 Salt efflorescence on the alcove ceiling above Open Area 35.
4.3 Snow Drift

4.3.1 Area

Upon arrival at Spruce Tree House on January 4, 2009, there had been no snowfall in the area for several days. At this time, there was a small amount of snow accumulation (less than one inch), along the floor of the alcove near the edge leading to Spruce Tree Canyon. Snow covered the stabilized path on which visitors to the site walk and was also evident inside the walls of some of the areas closest to the canyon edge. From south to north, these areas included Room 69, Open Area H, Room 59 and Open Area G, including the mealing bins located in the northwest corner of that space. In addition, there was snow present on the tops of the west walls of Open Area 23 and Room 69 and up against the exteriors of the west and partial north walls of Room 27 and the west wall of Open Area D.

There was no snowfall between January 4, 2009 and January 5, 2009, and although there appeared to be slightly less snow than on the previous day, the line of accumulation on January 5 stayed more or less the same. However, on the night between January 5 and January 6, 2009, the area received over 6 inches of snowfall. Accordingly, the line of snow accumulation on the morning of January 6 was quite different than it had been the day before. Upon arrival at the site, snow was visible within Open Area 35, throughout Open Area 23 and Room 69, and within Room 68 (figure 4.19). Snow also covered the western halves of Open Area H and Kiva H, the full interior of Room 59, and much of Open Area G, as well as the southwest quarter of Kiva G. A small amount of snow was present in Room 49 and against the north face of the partial wall just north of
Kiva F. North of this, the snow line did not encroach upon the architecture and covered only the visitor path, with the exception of the exterior faces of the north and west walls of Room 27 and the west wall of Open Area D. In addition, snow covered the large boulder on which Open Area 1 sits and had accumulated against the exterior west wall of this space (figure 4.20).

Figure 4.19 Snow accumulation in and around Rooms 68 and 69 and Open Areas 23 and 35.
Figure 4.20 Plan view of Spruce Tree House showing the line of snow accumulation at the site over a three-day period. The green line shows the advancement of the snow line after a large snowfall the night before. Base map courtesy of National Park Service.
4.3.2 Wetting/Drying as a Result of Solar Heating

In addition to the increased accumulation of snow, the visit to the site on January 6, 2009 allowed for the observation of another weather-related phenomenon at Spruce Tree House: the rapid snow melt and subsequent drying of the affected sandstone blocks as a result of solar heating. This was especially apparent around the edges of Kivas G and H and their corresponding open areas, which are towards the eastern boundary of the snowfall and therefore accumulated a thin layer of precipitation, approximately one inch thick.

As Spruce Tree House Alcove faces west, sunlight does not enter the space until mid-afternoon. Sunlight first hits the visitor path at the edge of the alcove opening and continues to make its way towards the architecture as the afternoon progresses. At the southern end of the site, it first reaches the architecture at approximately 2:30 PM. Between 2:30 PM and 3:30 PM on January 6, it was observed that the sun heated the sandstone edges of Kivas G and H enough to melt the snow that had accumulated along their rims (figure 4.21). Within one hour, the snow in these areas was melted and the surface of the stone on which it had accumulated was completely dry.

This observation is interesting for several reasons. It shows the degree to which the stone surface temperature in some areas of the site changes within a short period of time. The stone surface went from below freezing, so that the snow remained frozen above it, to a temperature warm enough to both melt the snow and dry the underlying stone within one hour’s time. In addition, it demonstrates that there is potential for wetting and drying weathering of the sandstone and plaster at the site. These fluctuations
in moisture can decrease rock strength and lead to a reduction in the bond strength between the grains that make up the stone. Fluctuations in the moisture content of the plaster can lead to the swelling and shrinking of the existing clays, potentially leading to fatigue and disintegration.

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Figure 4.21 Evidence of snow accumulation and subsequent snowmelt in Kiva H. Snowmelt, melting and drying of the stone in this location took less that one hour’s time.

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4.4 Water paths on the Alcove Ceiling

A final weather-related observation of Spruce Tree House has to do with the probable entry of liquid water into the alcove from the mesa top above. Although this action was not directly observed over the course of the visit to the site in January, evidence of its occurrence exists in the form of visible paths of water flow along the alcove ceiling. These are delineated by color changes in the alcove ceiling, where the characteristic black layer of soot has been washed away by water to reveal the light tan color of the alcove stone beneath, and in some areas by salt efflorescence or soil drips in vertical patterns along the alcove ceiling (figure 4.22). In addition, observations made from inside of the alcove during a characteristic late afternoon thunderstorm in the summer of 2008 verify that liquid water does in fact cling to the alcove ceiling in some areas and then drip down directly into the alcove when the tension holding it to that surface breaks. This occurs well past the roof edge of the alcove.

Patterns of water flow along the alcove ceiling also loosely correspond to areas in which runneling and soil wash were observed at the site. Areas where this is true include Open Area 35, Room 68 and Kivas E, F and G. A very distinct water path is visible leading to the inner face of the west wall of Open Area 24, where runneling in the plaster was observed on the side closest to the rear of the alcove (figure 4.23). This suggests that water is reaching that portion of the wall via flow along the alcove ceiling into the alcove interior. It is also interesting to note that areas of the alcove ceiling that lack visible water patterns correspond to relatively intact architecture and plaster decoration. For example, the east wall of Room 49 shows relatively little plaster and stone degradation, although it
receives no protection from adjoining walls and is located at the west edge of the site near the alcove opening. It also exhibits intact plaster embellishments. The alcove ceiling above this wall lacks evidence of water flow, although some evidence is visible directly to the north of the wall (figure 4.24).

Figure 4.22 Areas of the alcove ceiling at the north end of the site that no longer exhibit the characteristic soot layer and show salt efflorescence.
Figure 4.23 Alcove ceiling leading to the shared wall between Room 68 and Open Area 24. Arrow shows the water path leading to the area of runneling on the east face of that wall.
Figure 4.24 West wall of Room 49, showing relatively intact plaster and the absence of water paths on the alcove ceiling above. A presumed water path is visible just to the north (left) of the wall.
If one steps back to view Spruce Tree House Alcove from across Spruce Tree Canyon, larger patterns suggesting water flow are visible. The upper canyon wall shows large areas of dark coloring (figure 4.25). While on the alcove ceiling this suggests the absence of moisture, in the context of the canyon wall, it suggests the presence of moisture, which leads to biological growth in the form of molds and lichens. These dark areas generally correspond to the areas within the alcove that exhibit evidence of water flow. Such patterns suggest that liquid water is entering the alcove from the mesa top, either in the form of rainwater or melted snow.

Figure 4.25 View of the upper canyon wall above Spruce Tree House. Dark areas near the mesa top are areas of biological growth, and loosely correspond to areas that show extensive water paths on the alcove ceiling beneath.
One more connection to be made is that between the areas of supposed water flow and the topography of the alcove ceiling. In the cases where water apparently travels far into the alcove, the ceiling appears to be at a relatively steep angle, allowing water to cling to it for a distance before dropping to the ground or onto the architecture below. This is the case with the path above Open Area 24 and Room 68. The ceiling of the alcove above Room 68 is steep and exhibits clear water paths leading down from the alcove roof line. However, at the point where the ceiling is directly above the shared wall between Open Area 24 and Room 68, it’s angle changes sharply and it becomes almost horizontal. It is just under this point that the runneling described in the previous paragraphs is seen.

However, this is not to say that water does not flow into the alcove in areas where the ceiling slope is shallow. On the contrary, on surfaces of shallow slope, the water does not travel far into the alcove, but instead will collect at one point near the alcove opening until its own weight causes it to break surface tension and fall.

4.5 Conclusion

The pages above have outlined a number of observed conditions at Spruce Tree House alcove site. These conditions affect the plaster, the sandstone architecture and the geology of the alcove itself. While additional conditions not mentioned here may be present, those discussed in the above paragraphs represent the conditions which appear to be evidence of the most severe damage. The next step will be to put forth a hypothesis addressing the possible causes of each of these observed situations. This is essential for developing an appropriate monitoring plan for the site.
CHAPTER 5: HYPOTHESESIZED DETERIORATION MECHANISMS CAUSING OBSERVED CONDITIONS

Before implementing a monitoring plan at Spruce Tree House, the possible causes of the aforementioned conditions must be clearly defined and their measurement justified. A successful and cost-effective plan cannot be executed without a clear understanding of all possible mechanisms of deterioration, which will, in turn, lead to the most efficient design for monitoring the site. This thesis proposes that the presence of water at Spruce Tree House is the causative factor for the observed and potential conditions discussed here. In this chapter, the necessary and sufficient factors for each situation at Spruce Tree House will be discussed and their probable sources proposed.

5.1 Probable Mechanisms of Plaster Deterioration

5.1.1 Runneling and Soil Wash

The specific cause of runneling and soil wash is hypothesized to be liquid water dripping down from the alcove ceiling. The sources of this water are most likely rain and surface water runoff from the mesa top or high volumes of snow melt during the spring months. Evidence of this type of deterioration is most visible on the west walls of Kivas E, G and H, in rooms 2, 3, 27, 28, 68 and 69, and in Open Areas A, 1, 23, 24 and 35.

The relationship between runnels in the plaster at the site and areas of soil wash is as yet unknown. However, they often occur in close proximity to one another and it is possible that in many cases they occur concurrently or sequentially. The soil that forms a wash on a vertical surface may consist of disintegrated plaster that originated in an above
runnel. If this is the case, the areas of soil wash delineate where the water is flowing once it passes through the runnels and may indicate where future runnels will occur. The precise mechanism by which a runnel develops is not known; at some point water flowing as a film over a plaster surface evolves into an indentation in the plaster, which gradually deepens until the masonry substrate is exposed. Most likely plaster damage in the form of runnels is a result of dislodgement of the plaster particles by running water. However it may also be the result of the clay component of the plaster shrinking and swelling as it absorbs and loses water. This constant movement may lead to fatigue in the plaster binder, causing it to disintegrate and fall from the substrate. This phenomena has been seen at several other sites in the park, including Cliff Palace\textsuperscript{129} and Mug House.\textsuperscript{130} The presence of soil wash over a plaster surface may increase the chances of a runnel developing in that location by creating concentrated areas that stay damp for longer periods of time, allowing complete saturation of the plaster, thereby weakening it. However, this is not necessarily the case, and areas of soil wash may not be directly related to the creation of runnels. Further testing is needed to confirm or refute this connection.

At some point in the past, Park Service staff noticed the detrimental effects of falling water on the plaster of the areas mentioned above and attempted to mitigate the damage by installing silicone drip edges against the alcove sandstone above Open Areas 1 and A and also above Room 68 and Open Areas 23 and 35. The drip edges were

intended to prevent water that had previously run over the mesa edge and onto the architecture from entering the alcove by directing it towards the northern and southern boundaries of the site where it would not affect cultural materials. However, the efficacy of these drip edges was never tested or recorded after their installation and as a result Park Service staff are unsure as to whether or not they have been effective. The plaster beneath them still shows signs of runneling and soil wash, but whether this is new damage or damage that existed prior to the drip edge installation is unknown. A current map of these recent interventions is not presently available.

5.1.2 Plaster Loss and Salt Efflorescence

Plaster loss and salt efflorescence in the kivas at Spruce Tree House are most likely related to the capillary rise of liquid water within the kiva walls. The source of this water may be precipitation that collects in the kivas during rainfall or heavy snowmelt. If there is a sufficient amount to saturate the bases of the kiva retaining walls, it will travel upward through the porous sandstone and the earthen mortars and plasters of the structure by capillary action. As the material dries, the water will evaporate outwards through exposed surfaces of stone or plaster as the moisture content of the air within the pores of the materials moves toward equilibrium with the immediate surroundings. Any salts present in solution in the exiting water will be deposited either on the outer surfaces or inside the pores of the stone or plaster layer. These salts may then cause deterioration through hydration or crystallization pressure or through thermal expansion. If salts are not present in the liquid water, it can still cause damage to the plaster through continual swelling and shrinking of the material, causing fatigue and eventual disintegration. As
with the runneling and soil wash described above, liquid water introduced to the site from the surrounding environment and climate is most likely responsible for this type of deterioration.

5.2 Probable Mechanisms of Stone Deterioration

Plaster deterioration at Spruce Tree House is for the most part an easily visible and in some areas obviously active condition. However, it is also possible that there are several deterioration mechanisms in action that are causing stone at the site to decay, but that are occurring at such a slow rate that their effects are not quantifiable over the short period of time during which other observations in this thesis were made. Much of the deterioration and loss of masonry at Spruce Tree House occurred in the years just after the site was excavated in 1908. The site was partially reconstructed after its excavation and some walls were rebuilt, while others were left as partial ruins. As a result, it is impossible to tell what loss occurred in the past and was stabilized but not completely reconstructed and what loss has occurred since that original stabilization. Especially difficult to measure is the stone loss that may be taking place gradually, as opposed to the wholesale loss of building stones or the more obvious stone displacement that is sometimes evident. Nevertheless, these processes are an important part of the life cycle of the site and should be kept in mind when monitoring its deterioration and verifying possible causative mechanisms. Freeze/thaw cycling and salt crystallization are two processes that are most likely causing stone deterioration at Spruce Tree House but that have not been verified as active means of decay.
5.2.1 Freeze/Thaw Cycling

Freeze/Thaw cycling is a well-known and documented means of stone destruction. Multiple temperature variations near the freezing point of water within the stone can cause more severe damage than freezing that occurs once and remains at a constant temperature within the material. During the winter months, the temperature in and around Mesa Verde National Park can fluctuate on a daily basis around the freezing point. The average high temperatures during the months of November, December, January and February are above 40 degrees Fahrenheit, while the average low temperatures during those same months are well below freezing, with the highest being approximately 28 degrees Fahrenheit. Although changes in atmospheric temperatures do not necessarily translate to changes in the internal temperature of a building material, these severe diurnal fluctuations indicate that several freezing and thawing cycles can potentially take place at Spruce Tree House during the fall, winter and spring months, causing a range of deterioration effects, from superficial disintegration to the complete decay of material due to loss of cohesion along grain boundaries.

The vulnerability of stone to frost damage and freeze/thaw cycling depends on its

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porosity and pore structure and on the fact that water will expand within the stone’s pores as it moves from the liquid phase to the solid phase, resulting in a volume increase of up to nine percent.\textsuperscript{135} It is important to note that freeze/thaw action only causes severe weathering when water is present within the pores of the building material. This characterizes it as a moisture-related mechanism, as opposed to a mechanism related solely to temperature change.\textsuperscript{136} As water freezes within a stone it causes increased pressure within the pores, leading to cracks, fissures and joints, as well as the widening of some pore spaces, making them more susceptible to future water infiltration.\textsuperscript{137} Repeated freeze/thaw cycles can bring about fatigue within the stone from constant expansion and contraction, leading to increased friability and eventual disaggregation and wholesale loss of material.

Considerable diurnal fluctuations in temperature at Mesa Verde National Park satisfy one of the conditions necessary for freeze/thaw cycling to take place. Porous and well-bedded sedimentary rocks, such as the sandstone used in the construction of Spruce Tree House architecture tend to be the least resistant to frost action caused by freeze/thaw cycling.\textsuperscript{138} In addition, there is evidence that portions of the stone that form the alcove walls and ceiling are subject to wetness and partial saturation throughout the year. Observations made in January of 2009 show at least two instances of stone remaining partially saturated, even when no direct precipitation has occurred (figures 5.1, 5.2). This

\textsuperscript{136} Wiman, Sten. “A Preliminary Study of Experimental Frost Weathering.” \textit{Geografiska Annaler}. 45: 2/3 (1963), pg. 120.
evidence suggests that freeze/thaw cycling is a possible means of deterioration at Spruce Tree House and one that must be investigated and monitored in the future.

Figure 5.1 Stone at the south end of the alcove that forms the eastern boundaries of Room 70 and Open Areas 24 and 35. Stone appears to be damp, despite no apparent water source.

Figure 5.2 Damp boulder supporting the partial wall that is the western boundary of Room 70 and Open Area 24 and the eastern boundary of Open Area 23.
5.2.2 *Salt Crystallization*

Deterioration as a result of salt action is another moisture-driven mechanism that may be affecting the strength and durability of the building stone at Spruce Tree House. This process is particularly common in desert climates, such as that in which Spruce Tree House is located. As previously mentioned, the presence of salts has been recently observed at the site in conjunction with areas of plaster loss. While there is no evidence at this time of a connection between the plaster loss and the presence of salts, one likely exists and will need to be tested for in the future. Similarly, the presence of salts on the stone does not necessarily imply that they are the cause of stone deterioration; however it is well known that salts are a dynamic means of stone decay and future monitoring should be implemented to indicate whether the salts at Spruce Tree House are actively causing damage.

Salts in stone can originate from a multitude of sources, including air pollution, soil, past treatments or interaction between building materials. In some cases the stone itself may contain salts. No matter the source of the salts, water in either liquid or vapor form is needed to dissolve them into a solution that can penetrate and move through the stone. Once the salt solution is present within the building material, there are three means by which it can cause mechanical deterioration: crystallization pressure, hydration pressure and differential thermal expansion. Crystallization pressure depends

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on temperature and on the saturation of the salt solution within the stone. It occurs when the salt solution occupies a smaller volume within the stone than the crystals that precipitate out of solution upon evaporation of the water. This increase in volume exerts pressure within the pores of the stone and over time can cause fatigue and bond failure between grains. Hydration pressure depends on temperature and relative humidity and occurs when salts crystallize or recrystallize to form hydrated salts that are less dense and occupy more volume within the pores of the stone than did their dehydrated forms. Volume increase in some salts upon hydration can be up to 300 percent. Once this occurs, the mechanism of deterioration is similar to that which is caused by crystallization pressure.

Certain salts have higher coefficients of expansion than the materials in which they occur. While this may cause pressure and tension within stone that can lead to its deterioration, the extent to which this process effects a building material is unclear, and more research must be done in order to discover its potential as a destructive agent.

Freeze/thaw cycling and salt weathering are two processes which may likely be taking place at Spruce Tree House and causing deterioration of both the sandstone building units which make up the architecture of the site and the sandstone of which the alcove itself is composed. Both methods require the presence of water, and both take place at a relatively slow rate, meaning their consequences are not observable over a

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142 Ibid. Pg. 80.
145 Ibid.
short period of time. Future research and monitoring should be undertaken in order to investigate the effects these processes may be having on the cultural resources at Spruce Tree House and the extent to which they are causing its decline. This type of monitoring can then be used to design a preventive conservation scheme that will specifically address the problem of stone deterioration.

5.2.3 Wetting and Drying Cycles

Deterioration as a result of wetting and drying cycles has not been proven at Spruce Tree House; however the pattern of snow accumulation and the rapid solar heating of some portions of the site are two conditions which would allow for such a process to occur. The circumstances leading to this mechanism should be further observed and taken into account when designing a monitoring plan for plaster and stone decay.

5.3 Correlation Between Ceiling Topography and Apparent Water Damage Within the Alcove

Observations suggest that the angle of the alcove ceiling has an effect on how deep into the alcove water can travel. Certain areas of the ceiling that slope steadily inward at a relatively steep angle allow water to cling to them for a greater distance and therefore carry it towards architecture deeper within the alcove. In places where the ceiling slope becomes less steep, gravity begins to act against the surface tension of the water, pulling it away from the stone surface. As this happens, the rate of water flow slows and liquid water begins to pool in one area until its own weight forces it to drop to
the ground or to the architecture below. Areas of the alcove ceiling that do not exhibit a constant angle from the alcove opening inward potentially shed water at sharp discontinuities in slope, such as above the west wall of Open Area 24 (shown in Figure 30).

The strength of the surface tension of water is dependent on both temperature and on any substances that may be present in solution. This suggests that the points at which water falls onto the architecture in Spruce Tree House may change seasonally or with variations in ambient temperature. It is also possible that the presence of salts in the water causes inconsistency in the location of drip-related water damage.

As visible in figure 4.25, snowmelt dripping over the upper canyon wall during the winter sometimes refreezes in the form of icicles at the upper canyon edge. They appear to form only in the area where the scupper mentioned in Chapter 2 is located. Water is directed to this area by the diversion trench blasted into the slick rock of the mesa top by Fewkes and collects in large quantities there, freezing at lower air temperatures. The icicles prevent the melted water in this area from running down the alcove ceiling and dripping onto the architecture below by acting as natural drip edges that divert water from following the alcove ceiling. Although the icicles may begin to melt once the temperature rises again, it often takes several months for them to disappear completely due to their size. While the scupper does appear in this case to project water away from the alcove, it also creates an area of greater water saturation directly beneath it, evidenced in figure 4.25 by a stream of biological growth directly below the icicles. The large icicles also pose a safety hazard, as they are located directly above the visitor
While no direct correlation has been made thus far between the water paths on the ceiling of Spruce Tree House alcove, the topography of the alcove ceiling and the observed deterioration of the plaster below, this tentative hypothesis suggests a likely connection between the three observed phenomena at the site.

5.4 Possible Sources of Moisture Ingress

The observed conditions and their probable causative mechanisms described above share one important aspect: the necessity of moisture to initiate and drive the deterioration process. Any scheme for the preventive conservation of Spruce Tree House must therefore begin with an identification of the sources of moisture at the site.

As explained by the chart developed by John Straube to discuss the wetting, drying and storage of moisture within buildings, water can enter a site in four ways: as liquid water through rain, as liquid and vapor through soil and groundwater, as vapor from human activity and the atmosphere and as built-in liquid and vapor in the construction materials.146

Because the architecture at Spruce Tree House was constructed several centuries ago, built-in moisture is most likely not a current source of water at the site. Generally, groundwater refers to water that originates in the soil. The amount of groundwater that is available to infiltrate a building is dependent on a variety of circumstances, including soil composition, depth of the water table, and climate conditions. The floor of Spruce Tree

House Alcove is shale, sandstone and soil fill and contains no active source of groundwater. However, precipitation and atmospheric water vapor are viable options for moisture sources at the site and may be entering the architecture by means of gravity and adsorption, respectively.\footnote{\textsuperscript{147}}

As has been previously discussed, liquid moisture has been observed entering the alcove as a result of precipitation in the form of rain. Although it has not been directly observed, it is also possible that liquid water enters the site from above as a result of snowmelt in the spring. Water rising through masonry walls at Spruce Tree House is likely not originating in the ground itself, but is being supplied as liquid water through precipitation, which collects in the lowest areas of the site, the subterranean kivas. Incidentally, these spaces are where the majority of plaster loss and salt efflorescence have occurred.

Water vapor from the atmosphere is another potential source of moisture at the site. Although the area’s climate is relatively dry and arid, relative humidity does increase in the winter months as temperatures decrease.\footnote{\textsuperscript{148}} Water vapor may enter into the building materials at the site through adsorption or through condensation and subsequent absorption into plasters and building materials. Once inside the pores of the materials, the water vapor can cause destructive effects such as wetting and drying, freeze/thaw cycling, and salt dissolution.

\footnotetext{\textsuperscript{147}} Ibid.
5.5 Conclusion

The probable causes of deterioration discussed above should be targeted in any plan for monitoring environmental conditions and their effects on the architecture of Spruce Tree House. The hypotheses stated in this chapter must be validated or refuted by monitoring before any form of intervention is initiated to slow their progress. The following chapter will discuss possible tools and methods of testing these hypotheses.
Figure 5.3 Flow chart showing possible sources of moisture at Spruce Tree House and the types of deterioration they most likely cause. Adapted from Straube’s chart on the wetting, storing, and drying of moisture in buildings.
CHAPTER 6: PROPOSED MONITORING PROGRAM TO VALIDATE HYPOTHESES

6.1 Program Objectives

This thesis has put forth the hypothesis that the presence of water at Spruce Tree House is the necessary and sufficient factor behind the aforementioned processes of degradation at the site, causing both plaster and stone deterioration. A monitoring program for the site must therefore focus on identifying and confirming moisture sources, their loci of transport within the site and the estimated quantities of moisture they introduce. The extent of resultant loss of historic fabric must also be monitored, so that strong correlations in degree may be established and causality confirmed.

Once this information is compiled, an appropriate program of prevention and intervention can be developed and implemented; this program would address not only the effects of plaster and stone deterioration at the site, but also reduction or elimination of the underlying causes.

6.2 Conditions to Monitor

At Spruce Tree House, devices should be put into place in order to observe over time the deteriorated areas discussed in the previous chapter. This chapter will revisit those areas, discuss the usefulness of monitoring proposed causes of deterioration and recommend how that may be accomplished. Certain mechanisms will prove too unreasonable in scope and scale to measure with the tools available. These will be discussed and justification for forgoing their observation with monitoring equipment will
be put forth. All mechanisms should continue to be observed regularly with the naked eye in order to identify any substantial changes in condition that may occur unexpectedly.

6.2.1 Runneling and Soil Wash

Confirmation of runneling and soil wash at Spruce Tree House must show that liquid water is still reaching the already deteriorated areas and causing further damage. Initially it will not be necessary to quantify the amount of water that may be reaching the architecture, but only to verify its presence. This requires the simplest of monitoring tools: visual evidence. Because Spruce Tree House is remote, and because it would need to be observed at specific times (i.e. during and after rain events and snow melt), it would be logical to use a visual recording method that could collect data over a period of time which could then be downloaded and viewed remotely.

A robust camera made for outdoor use would be a practical tool for accomplishing this goal. Many cameras able to withstand open-air conditions are available today for recreational use by hunters and birdwatchers. Such cameras can often be activated manually or remotely by the user or can be programmed to a motion-activated setting. One such example is the WSCA01 Birdcam, manufactured by WINGSCAPES.149 This camera captures JPEG images and videos and can store up to 4 GB of data. It is battery operated and can be activated by remote control and set to a time delay. In addition, it can capture multiple images during each motion-activated event. A similar product made especially for hunters interested in viewing active wildlife features

a 6.0 Mega Pixel Nikon camera with a wide-angle lens in a waterproof casing.\textsuperscript{150} It runs on one 9-volt battery that can last for up to a year if the camera is used only in motion-detection mode.

Although images prompted by nearby movement are not directly useful to the monitoring program suggested here, the principle of capturing an image based on an external event is. In the case of Spruce Tree House, a camera that was activated by a rain event, or by the accumulation of a certain amount of water on top of the mesa, would provide a direct correlation between weather events such as precipitation and the presence or absence of water within the alcove, specifically on the walls that present evidence of runneling and soil wash.

This method would be helpful if the camera were connected to a sensor measuring the amount of rainfall accumulation outside of the alcove. Once the sensor reached a certain threshold, the camera could be activated and would continue to take photographs until the end of the weather event. A weather station or rain monitor located directly above Spruce Tree House would provide the clearest correlation between rainfall and water infiltration into the site. Triggering a camera to record the presence of snowmelt is a different challenge. As seen during the January 2009 site visit, large amounts of snowfall do not appear to infiltrate the alcove to a great degree. It is the melting of snow on the mesa above that potentially causes the runnels and soil wash discussed in this thesis. In this case, the cameras should be triggered once the temperature rises to a certain point during months when snow is on the ground. In this way, they will record whether or

not the melted snow is reaching the interior of the alcove.

If a reliable connection cannot be made between the camera and a rainfall sensor, remote control activation by park personnel is an option. The majority of rain events at Mesa Verde occur in the afternoons during the months of July and August with surprising regularity. At these times there are at least two park rangers on duty at the site. Rangers who are already scheduled to be working at Spruce Tree House during the summer could be trained to operate the cameras by remote control at the beginning and end of each rain event. The cameras could be programmed to take pictures at regular intervals until the rangers deactivated them. This option has the advantage of recording specific areas of the site during all rain events, not only those that break through the specified threshold. Data from the captured images could then be compared to information from park weather stations to determine the magnitude of the rain event required to cause damage. Issues of reliability and consistency must be taken into account when considering this method. Park staff may not always be able to perform the discussed monitoring responsibilities. As a result, some data may not be collected, which in turn may skew any results of later analysis.

An additional option for continuous visual observation of Spruce Tree House is the installation of a wireless webcam able to stream video or still images directly from the site to the internet via cellular network. Originally developed for security purposes, such cameras are now widely available and can be used in extreme outdoor conditions. One such camera is the NetCam© Digital Internet Camera and Server, available from StarDot Technologies in California. This standalone network camera can be housed in a
rugged outdoor enclosure allowing it to function at temperatures as low as -40°F and as high as 120°F. It automatically transmits live images to the web at a rate as fast as one frame per second. Images can be viewed in real-time on a website or downloaded to a remote server and archived for later analysis. The least expensive model offered by StarDot Technologies requires access to a power source, a limited number of which are available at Spruce Tree House. More complex models can run on battery or solar power and can film at higher resolutions during the day and night.151

DigitalXtraction, Inc., located in Rochester, New York offers a similar camera, the SCIRCt1, which stands for “self-contained internet remote camera.” This camera also captures images continuously and transmits them via cellular network to an IP Address where they can be viewed remotely or downloaded to a remote server. Although the SCIRCt1 is battery powered, the battery lasts for only five days before it requires recharging. This may pose a problem at a remote site such as Spruce Tree House, which would necessarily rely on changing seasonal personnel to regularly change and recharge batteries. However, the camera can also be plugged into a direct power source, which may be an option at Spruce Tree House, or can be attached to an available solar panel. The camera requires access to the AT&T Wireless network in order to transmit data to the internet, another limitation that will have to be addressed.152

The most severe runneling and soil wash damage occurs in Kivas E, G and H, on the exterior walls of Open Areas 1 and A and in and around Room 68. These would be

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priority spaces to monitor with one or several of the camera systems described here. They are also well dispersed within the alcove and therefore could represent the effects of liquid water over a relatively large area. Secondary spaces to monitor with cameras if time and budget allow would be Open Areas 23 and 35 and Rooms 27 and 28. In order for monitoring to be effective, it would have to take place over at least two years’ time, allowing for the identification of seasonal patterns.

6.2.2 Plaster Loss and Efflorescence

The previous chapter hypothesizes that plaster loss and efflorescence at the base walls of Kivas E, G and H are driven by liquid water pooling on the kiva floors and saturating the extant stone and plaster. As the water travels through the materials, it can cause them to shrink and swell, reducing durability, or can deposit soluble salts as it evaporates. Both processes have the potential to cause material degradation and loss over time. A plan for confirming these actions would include at least two monitoring components: regular visual observation and conditions recording and measurement of soil moisture content.

The first component requires simple visual recording of specific areas that appear to be suffering from plaster loss over time. Careful documentation should be made at least seasonally in the same areas in order to discern whether the amount of extant plaster has remained the same or has diminished. This component would be less effective for determination of change in salt patterns, but could also be used for this purpose.

The second component of this part of the monitoring program would involve installation of soil moisture sensors in Kivas E, G and H in order to confirm both that
water is pooling at their floors and that it is rising up through their masonry walls. Soil moisture sensors could be placed inside the eastern halves of the kivas near the juncture of floor and wall, as that is where the most severe damage occurs.

One potential problem with this proposal is that the floors of all three kivas are made of either bedrock or puddled adobe, both of which may yield problematic results if soil moisture sensors are used to detect water on or within them. There are two possible solutions to this problem: cut cores out of kivas with non-historic or stabilized floors that can then be filled with soil to house a sensor or cover the kiva floor with a proxy material such as sand and embed the sensors in that material.

Soil moisture sensors should be placed in the walls of the kivas at various heights in order to confirm the occurrence of capillary rise. Although it would not be possible to place the sensors directly within the masonry units of the walls, they could be placed within mortar joints. The park may not approve of the removal of original mortar to allow for installation of sensors, however, non-historic repair mortar could be removed; alternatively sensors could be placed in already empty joints and surrounded by a compatible soil mixture.

At least three sensors should be placed in each wall: one within the area of total plaster loss, one at its upper boundary and one above the area of loss. If they are placed within the same vertical line, results from all three sensors should demonstrate whether or not water is traveling upward through the wall. The sensors may also show whether the moisture is traveling beyond the current area of loss, suggesting incipient loss.
As previously mentioned, it may be necessary to cover kiva floors with a proxy material such as sand in order to obtain valid results from soil moisture sensors. While this will assist in providing helpful floor moisture readings, it may negatively affect the results from the sensors embedded in the wall, as the proxy material may absorb more water than the kiva floor and provide less water for capillary action. This may result in sensor readings that do not reflect the actual situation of a kiva that has not been modified for monitoring.

One possible solution to this problem is to monitor the three kivas differently and use the results from each design to confirm or negate the results of the others. For example, a proxy material with an embedded sensor could be placed into one kiva with no sensors in the walls, while a second kiva could have monitors in the walls but no floor monitor and no proxy material. The third kiva would combine proxy material, a floor sensor and wall sensors, thereby allowing a correlation to be made between soil moisture and wall moisture and also demonstrating whether or not the proxy material plays a major role in reducing capillary rise.

Onset Computer Corporation currently offers several types of data loggers that can be connected to soil moisture sensors of varying sizes, most of which are small enough to be used discretely at Spruce Tree House without causing damage to original fabric. Data can be downloaded from the loggers either directly into a computer or can be transmitted via cellular network to the internet, where it can be monitored in real time.153 Cellular communication may not be practical at Spruce Tree House, as it is a remote site.

that does not easily receive cellular signals.

One available tool is the HOBO® U30-GSM cellular communications Data Logger. This logger has an operating range of -4ºF to 104ºF and can accommodate up to ten external sensors. It is housed in a weatherproof enclosure and can be powered by optional solar panels or by an electrical power source. Two external soil moisture sensors compatible with this data logger are the S-SMB-M005 and S-SMC-M005 Soil Moisture Smart Sensors. These sensors are similar in that they are small (3.5 to 6 inches in length) and lightweight (approximately 6.7 ounces). The S-SMB-M005 sensor is a flat rectangular panel with a thin profile, allowing for easy installation and measurement of a cross-section of soil. The S-SMC-M005 sensor has two metal tines, which can be embedded into the soil to be measured. Both sensors operate between 32ºF and 122ºF, a smaller and higher range than the data logger to which they would be attached. The Onset Computers website explains that, while the sensors “can safely operate at below-freezing temperatures…the soil moisture data collected at these extreme temperatures is outside of the sensor’s accurate measurement range.” Readings taken every fifteen minutes should provide sufficient information about moisture conditions at the selected sample locations, although this period can be altered if results prove inconclusive once monitoring has commenced. Data should be downloaded monthly from the logger as a

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backup to the real-time data being transmitted through the cellular network to the internet.

The three kivas to be measured using the soil moisture sensors are within sight of visitors to Spruce Tree House, although none of them are directly accessible to the public. It will be difficult to install the devices invisibly at useful locations in the kivas without causing substantial damage to original fabric. However, because visitors are not allowed to the site without supervision by park staff, the visible monitors could be used as interpretive tools to teach about the complex issues of conservation at an archaeological site. Although this may detract from the authenticity of the site as an ancient dwelling, it will inform visitors of current concerns at the park and make the place more relevant to their lives.

6.2.3 Stone Deterioration

Freeze/thaw cycling, wetting and drying cycles and salt crystallization are three mechanisms already mentioned that may be causing deterioration of the masonry units and alcove sandstone at Spruce Tree House. However, designing a program to monitor this type of decay is difficult, as it occurs slowly and there is no substantiated evidence of the aforementioned processes at this time. It would be impractical to attempt to monitor these conditions having no idea where they might be taking place in such a large and variable site. However, the presence of certain necessary and sufficient factors can be confirmed through monitoring, which, in turn, can lead to more specific observation strategies.

Stone temperature is a parameter that can be measured quite easily; the challenge
lies in choosing sample locations that are representative of the whole site. These locations would come from the smaller population of stone units within the alcove that are exposed to water, which is necessary for the three stone deterioration mechanisms discussed here. In that smaller group, some may never reach the low temperatures necessary to initiate freeze/thaw cycling. If the wrong areas are chosen for monitoring, they may yield false results and mistakenly demonstrate the stability of stone at the site, when in fact other areas may be subject to conditions conducive to damage-causing combinations of moisture and temperature.

The presence of salt within the stone or an external source of salts would need to be proven in order to propose that deterioration by salt crystallization was taking place. Although non-destructive tests are currently being developed to test for salts within varying materials\(^{158}\), many of the existing tests use destructive means and would not be acceptable for use at Spruce Tree House. Complicating the matter further, as with the freeze/thaw cycling, showing the existence of the two necessary components, soluble salts and water, does not conclusively prove that damage by salt crystallization is occurring. It is currently impractical to install monitoring equipment for the purpose of confirming salt crystallization action, as there is no observed condition that can be attributed solely to this mechanism. More research and observation must be done in order to ensure that any proposed monitoring plan would focus on the correct areas and not yield misleading data as a result of poorly chosen sampling locations.

Keeping these limitations in mind, it would be useful to measure ambient temperature, stone surface temperature and relative humidity within the alcove to get an idea of the patterns created as a result of the alcove microclimate. Such measurements could be taken at five points within the alcove: one each in the north and south areas of the alcove, one near the sheltered rear section of the alcove, one near the exposed alcove opening and one at the approximate center of the site. Resulting data may reveal the presence or absence of the factors necessary to initiate certain deterioration processes, such as condensation and freeze/thaw cycling.

In addition to the specific variables that can be measured within the alcove, there are a number of general climate variables that can be measured in the area, such as temperature and relative humidity. Measurement of ambient temperature will confirm when it is warm enough to melt snow cover on the mesa top, a possible source of moisture within the site. Ambient relative humidity should also be measured in order to confirm or refute the possibility of condensation or adsorption of liquid or vapor water on the masonry of the site or on the natural alcove walls; these actions can cause increased salt cycling within the stone. Comparison of ambient relative humidity with historic dewpoint temperatures may provide insight as to whether condensation at Spruce Tree House is a probable mechanism of water entry.

Another component of a general monitoring plan for the site would be the observation and documentation of light patterns within the alcove. As of now, there is no accessible record of where sunlight reaches within the alcove or how the light patterns change seasonally. This could be created through regular photographic documentation, or
through the use of complex modeling software. Knowledge of the patterns of sunlight reaching the architecture within Spruce Tree House alcove will provide further evidence to support or refute the hypothesis that solar radiation affects the building stone at the site.

The most useful monitoring that can be done at present in terms of verifying or negating the aforementioned deterioration processes is regular and continuous observation of the site. Because there has been no previous conditions assessment performed at Spruce Tree House, and because there is no regular program of visual observation or image recording, it is unknown whether or how much conditions have changed over time. A program should be put into place that involves taking regular photographs of all areas of the site that are subject to water infiltration. In this manner, any changes that may be taking place will become evident. More complex measures can then be taken to discover what is causing changes and whether or not those changes are severe enough to warrant intervention.

6.2.4 Measuring the Alcove Ceiling

The previous chapter introduced the hypothesis that variations in the slope of the alcove ceiling correlate to areas of water damage on the plaster and architecture below. Observations using a level or plumb bob should be used to confirm the correlation between the locations of water paths on the alcove ceiling and water damage found within the site.

Although there may be no tools available to directly measure the angle of the alcove ceiling, especially considering its height and access issues, it is relatively easy to
measure such angles indirectly. A laser-based measuring device, such as the DISTO™, manufactured by Leica Geosystems\(^\text{159}\) could be used to measure both the height of one point on the ceiling and its distance from a given point. The same information could then be measured for a second point in the same east/west axis as the first. The difference in the heights, \(\Delta y\), over the difference in the distance from the constant point, \(\Delta x\), would equal the slope of the line between the two measured points. This simple method can be used to determine the slope of several areas of the alcove ceiling and from this information an observer could determine whether or not they correlate to the visible water paths on the ceiling and to observed damage below.

### 6.3 Conclusions on Monitoring at Spruce Tree House

The goal of a monitoring program installed at Spruce Tree House should be to confirm the occurrence of certain deterioration mechanisms before developing an effective and minimally invasive intervention to slow these mechanisms. The existing conditions at the site provide the basis for what can practically be measured and what should be more thoroughly researched before monitoring is implemented. Sampling locations for monitors should be chosen on the basis of careful observation of existing conditions. Architecture that may be affected by slow-moving processes should be observed over time, in order to choose sampling locations that will be representative of the site as a whole. The occurrence of such slow-moving mechanisms should be confirmed before resources are used on their monitoring.

CHAPTER 7: CONCLUSION

In an ideal world, the development of a monitoring plan for any historic building or archaeological site would be undertaken only after the completion of several essential preceding steps. These include:

- Archival research on the site to determine its past contexts, use, environment and intervention history;
- Detailed and thorough recording of current conditions at the site, including visual evidence such as photographs or drawings;
- Identification of the necessary and sufficient factors for the creation of current conditions; and finally
- Development of hypotheses as to the probable deterioration mechanisms leading to current conditions.

Unfortunately, due to limitations on time, finances, personnel and accessibility, these steps may not occur in sequence. How to design an effective monitoring plan when one does not know what parameters need to be measured is often the problem faced by preservation professionals when deciding how to act as responsible stewards of the historic resources in their care.

In this situation, what is most important is that existing conditions are critically observed and their possible causes hypothesized. Identification of active versus non-active mechanisms is also important. With at least these steps completed, the risk of spending limited resources on an impractical system of measurement is greatly reduced. Before undertaking the design and implementation of any monitoring program, one must take into account the difficulties presented by a lack of necessary and valuable information. Without the aforementioned steps to inform the program, monitoring can be inefficient, and may not produce useful results.
Spruce Tree House has a long and varied history of documentation and intervention. However, much of this has been poorly recorded, and follow-ups on past interventions have been few and far between. For this reason, the chief causes of deterioration at the site have persisted since its excavation in 1908. The fact that its architecture and much of its plaster are still present after nearly 800 years is a testament to the skill of its creators.

If responsible management of Spruce Tree House is to continue, it is crucial that the necessary and sufficient factors for deterioration there are identified, and then slowed or halted completely. The monitoring program set forth in this thesis aims to do just that, providing guidance for the site’s stewards to use when developing interventions that may be costly or pose a threat to original fabric. However, accomplishing this goal was difficult, especially with the limitations of missing information, inaccessibility and a general lack of knowledge of previous interventions at the site. For this reason, the program outlined here may need to be revised in the future if new information surfaces or discoveries regarding environmental impacts on the site are made. In fact, any monitoring system should recognize the inevitability that sites are not static. As they change over time, so must measures taken for their preservation.

There is a good deal of information that is not currently available about Spruce Tree House that may emerge or be produced in the future and necessitate at that point modification of the plan proposed here. These include an accurate map of where the roof line of the alcove lies in relation to the architecture beneath. A model of sunlight penetration would also be helpful, as would a diagram of where the silicone drip edges
installed by the National Park Service were placed. Further information on past stabilization and interventions may also call for changes in the monitoring plan.

A current and thorough conditions assessment of Spruce Tree House will be a critical part of any future plan for the site’s care and management. In depth knowledge of how the site stands today will allow for comparisons to be made in the future, bringing to light changes and possibly new mechanisms of deterioration. The absence of current and past conditions assessments was a major obstacle in the development of the monitoring program set forth here.

The conception of any diagnostic tool for use at a historic site is dependent on the unique and defining characteristics of that site. There is no one plan that can be used as a panacea and still be effective. Literature on the subject shows that every site poses distinct challenges; these are sometimes solved by simple means, but often require complex programs of measurement that necessitate stewards to “think outside the box.” Tools that can be used for monitoring historic sites are rarely designed specifically for preservation use. As such, preservation professionals must look to other fields for helpful equipment. In the case of Spruce Tree House, suggested tools come from the fields of security, agriculture and construction, as well as hobbies such as hunting and bird watching. New technologies are being developed constantly, meaning that monitoring programs may be rendered obsolete if they are not reviewed and updated on a regular basis.

Finally, a monitoring program serves no purpose at all if it is not consistently maintained and if the data it produces is not used effectively. Implementing the plan
discussed here would only be the first step in a much longer process if Spruce Tree House is to be managed successfully. Data must be consistently and carefully collected over a long period of time. It must be analyzed for patterns related to causative factors of deterioration at the site. Only then can appropriate means of intervention be executed.

Spruce Tree House is a unique site, not only within Mesa Verde National Park, but also within the United States. It is an excellent example of Ancestral Puebloan cliff dwelling architecture and has retained a great deal of its original fabric. If it is to remain intact, the National Park Service must be proactive not only in stabilizing the site and responding to emergency mitigation needs, but also in discovering the underlying causes of degradation there. Only then can these causes be responsibly addressed in order to ensure that this model of ancient Native American architecture remains standing for the next 800 years.
BIBLIOGRAPHY


APPENDIX A:

HISTORIC AND CONTEMPORARY PHOTOGRAPHS OF

SPRUCE TREE HOUSE
Photograph dated April 1935. Shows southwest quarter of Kiva E before the surrounding alcove floor was stabilized. Attributed to Markley. Courtesy of Mesa Verde National Park Archives.

Close-up view of stabilized alcove floor surrounding Kiva E. Area where seam appears is highlighted in both photographs.


View looking east across Open Area E at the second and third stores above Room 48.

Spruce Tree House after stabilization. Date and Photographer unknown. Courtesy of Mesa Verde National Park Archives.
Historic photograph of Spruce Tree House across Spruce Tree Canyon. Date unknown. Courtesy of Mesa Verde National Park Archives.

Current view of Spruce Tree House across Spruce Tree Canyon.
APPENDIX B:

AVAILABLE ONLINE MANUALS FOR MONITORING DEVICES
This product is covered by one or more of the following US Patents: 6735387, 6768868, and 6834162. Other patents pending.

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# Table of Contents

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Welcome

Using technology to automatically detect wild birds is a science that requires some artfulness on the part of the user. Wingscapes has designed the BirdCam to be simple for beginning users, but also to be flexible enough to work in a variety of conditions.

The easiest way to get started is to...get started. Refer to the “Quick Start Guide” in the following pages and begin experimenting with a simple setup. (We think the best way to get started is to setup the BirdCam at ground level — with bird seed scattered 2 to 4 feet in front of it.)

Weather, bird species, feeder type, feeder placement, and other factors all influence BirdCam performance. Custom settings allow you to optimize the BirdCam for a variety of conditions. Finding the correct combination of settings and BirdCam placement for a given situation may require some experimentation and practice. At any time, you can reset the BirdCam to its factory default settings in the SETUP menu.

Please take a moment to familiarize yourself with this guide and the basics of operating the BirdCam. If at any time you need assistance or have questions about the BirdCam’s operation, please visit the support section of our website (www.wingscapes.com) or contact us via e-mail or phone.
Quick Start Guide

The following steps outline the quickest way to begin using your BirdCam. We strongly recommend that you read the remainder of this user's guide before using your new BirdCam.

1. Remove BirdCam from packaging.
2. Remove rear battery compartment door and insert four new D-cell batteries.
3. Mount the BirdCam so that it is aimed where a bird will land (preferably within 4 feet). Secure the BirdCam with the included stretch cords.
4. Adjust the focus ring to match the distance between the BirdCam and the target.
5. Move the BirdCam’s power switch to the ON position.
6. Close the door and secure the latches of the BirdCam.

What Happens Then?
The BirdCam will be in the MODE menu. After a 30-second countdown, the BirdCam enters AUTO mode using the factory default, EASY-PHOTO settings. After another 30-second countdown, the BirdCam will watch for and photograph birds until either the memory is depleted or the batteries are drained.
Getting to Know the BirdCam

The following sections will help you familiarize yourself with the Wingscapes BirdCam.

What’s in the Box

• BirdCam
• Stretch cords for mounting (2)
• USB cable for downloading photos and videos to a computer
• TV Out cable for viewing photos and videos on a TV
• User’s Guide
• Warranty Registration Card
Getting to Know the BirdCam

- Camera lens
- Shutter button (in MANUAL mode)
- Loop for mounting and/or aiming
- Cutaways for attaching stretch-cords
- Security hasp for padlock (not included)
- Latches
- Infrared sensor
- Display
- Photocell (turns BirdCam off at dusk / on at dawn)
## Getting to Know the BirdCam

### Wingscapes BirdCam Specifications

<table>
<thead>
<tr>
<th><strong>Operational Modes</strong></th>
<th>AUTO, MANUAL, or TIMELAPSE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Housing</strong></td>
<td>Weather-resistant and lockable</td>
</tr>
<tr>
<td><strong>LCD Status Display</strong></td>
<td>Operating Mode, Photos/Video taken, Photos/Videos remaining, Battery strength, BirdCam status</td>
</tr>
<tr>
<td><strong>CMOS Sensor</strong></td>
<td>3.1 Megapixel</td>
</tr>
<tr>
<td><strong>Built-in Memory</strong></td>
<td>32 MB</td>
</tr>
<tr>
<td><strong>Memory Card</strong></td>
<td>Up to 4 GB SD card (optional)</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>JPEG (Photos), AVI (Videos)</td>
</tr>
<tr>
<td><strong>Image Output</strong></td>
<td>USB OUT, TV OUT, SD Card (optional)</td>
</tr>
<tr>
<td><strong>Auto/Timelapse Delay</strong></td>
<td>Variable: No Delay - Daily</td>
</tr>
<tr>
<td><strong>Multiple Shots / Event</strong></td>
<td>1-10 for Photo; 1-3 for Video</td>
</tr>
<tr>
<td><strong>Lens</strong></td>
<td>multi-element glass, fixed aperture f/2.8</td>
</tr>
<tr>
<td><strong>Lens Field of View</strong></td>
<td>52 degrees (roughly equivalent to a 46mm focal length in film camera)</td>
</tr>
<tr>
<td><strong>Shutter Speed</strong></td>
<td>1/8 - 1/4000</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>18 inches - infinity</td>
</tr>
<tr>
<td><strong>Infrared Sensor</strong></td>
<td>Passive</td>
</tr>
<tr>
<td><strong>Max. Detection Distance</strong></td>
<td>8’ for birds, 32’ for humans</td>
</tr>
<tr>
<td><strong>Detection Field of View</strong></td>
<td>22 degrees</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>with batteries – 2 lbs. 8.4 oz</td>
</tr>
<tr>
<td></td>
<td>without batteries – 1 lb. 4 oz</td>
</tr>
<tr>
<td><strong>Power Supply</strong></td>
<td>4 D-cell Batteries</td>
</tr>
<tr>
<td><strong>Duty Cycle</strong></td>
<td>4 weeks average</td>
</tr>
<tr>
<td><strong>Laser Aim</strong></td>
<td>Class II (READ WARNINGS)</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>9” H x 3 5/8” D x 5 1/2” W</td>
</tr>
<tr>
<td><strong>Optional Accessories</strong></td>
<td>Mounting Bracket, AC Power adaptor, Remote Control</td>
</tr>
</tbody>
</table>
Getting to Know the BirdCam

Memory Capacity & Storage
Your BirdCam has two types of memory:

1. **Internal memory (32 MB)**
   When the BirdCam is used without an SD memory card, images are automatically stored in the BirdCam’s internal memory. The images stored in internal memory are only accessible when the BirdCam is connected to a computer or TV.

2. **Optional SD Memory Card (sizes up to 4 GB)**
   When the BirdCam is used with an optional SD memory card, images are automatically stored on the SD memory card. The images stored on the SD card are accessible when the BirdCam is connected to a computer or TV, or by using an optional SD card reader.

**IMPORTANT NOTES ABOUT SD MEMORY CARDS:**

a. Always turn the unit off when inserting or removing an SD card to avoid damage and ensure that the BirdCam properly updates the memory information.

b. When an SD card is inserted in the BirdCam, any photos stored in the BirdCam’s internal memory become inaccessible, but are not lost. When the SD card is removed, images in the internal memory become accessible again.

c. Number of pictures or videos stored is determined by the card capacity with a maximum of 7500 files.

d. For error messages related to SD card problems, see troubleshooting section.
Getting to Know the BirdCam

Memory Capacity & Storage continued

<table>
<thead>
<tr>
<th>Photo Quality</th>
<th>Included (onboard)</th>
<th>Optional SD Card 256MB</th>
<th>Optional SD Card 512MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW 640 x 480</td>
<td>339</td>
<td>2,993</td>
<td>5,995</td>
</tr>
<tr>
<td>MED 1328 x 996</td>
<td>92</td>
<td>812</td>
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<tr>
<td>HIGH 2048 x 1536</td>
<td>37</td>
<td>327</td>
<td>653</td>
</tr>
<tr>
<td>VIDEO CLIP</td>
<td>7</td>
<td>62</td>
<td>124</td>
</tr>
</tbody>
</table>

*Estimate of average capacity. Image size varies depending on image properties.

Battery

The BirdCam runs on four D-cell batteries. When inserting fresh D-cell batteries, ensure that polarity (+/-) is correct. Battery life is approximately 4 weeks, depending on outside temperature and BirdCam usage. If longer run times are required you can use an optional external 12Volt power source.

When the BirdCam is active, the amount of remaining battery capacity is displayed as a percentage. When display reads B20% (or lower), replace batteries.
Photocell

The BirdCam is equipped with a light-sensitive, photo-cell which constantly measures available light. In very low light, the photo-cell forces the BirdCam into NIGHT mode. This conserves battery power when there is not enough light to take pictures. When the light level increases, the photo-cell will ‘wake-up’ the BirdCam, which will resume operations according to current settings.
Mounting the BirdCam

The BirdCam has been designed to offer a balance of mounting flexibility and ease of setup. There are several easy ways to mount the BirdCam. With some ingenuity, you should be able to aim the BirdCam almost anywhere a bird will land.

Important Mounting Considerations:

- The BirdCam needs sufficient daylight to function. It will not operate properly in a dark situation (e.g. – inside a nest box).
- When mounted, the BirdCam should not move (e.g. – do not ‘hang’ the BirdCam).
- Position the BirdCam so there is no obstruction – like branches or leaves – between the BirdCam and its target.
- Remember, unlike bird feeders, the BirdCam does NOT need to be mounted where you can see it. It watches birds when (and where) you cannot.
- Think about image composition. Frame your shot. Position the BirdCam so the background is appealing.
- Consider the sun’s position. Images will look better if the BirdCam is positioned between the sun and the target.

See figure below.
Mounting the BirdCam

About the Laser Aiming Device
The BirdCam’s laser aiming device will help aim the BirdCam accurately. When turned ON, the laser projects a red dot where the center of the image will be.

IMPORTANT: Looking into the laser may be hazardous to the eyes. Do not stare into the beam or aim at other people. Read the warning label on BirdCam before operating the laser.

To operate the laser aiming device:
1. With the BirdCam door open, use the MODE button to display <ENTER SETUP> and press ▶ to enter the SETUP menu.
2. With the BirdCam pointed toward its target (and away from people), press the LASER AIM button. This will activate the laser aim while you adjust the positioning on the BirdCam.
3. To turn off the laser and re-enter SETUP mode, press the LASER AIM button again. If the laser is not turned off manually, it will time-out after 90 seconds.
Mounting the BirdCam

Scenario #1 – Birds on the Ground
Perhaps the easiest way to set up the BirdCam is to simply position it securely on the ground and place some bird food in front of the BirdCam. This is an excellent way to get close-up photos and videos of many birds that do not regularly visit feeders.

Scenario #2 – Mount with Included Stretch Cords
The two included stretch cords can be used to attach the BirdCam to a tree or large post. To do this, simply hook the cords to the recessed cutaways on the back of the BirdCam. This is the best way to target a feeder hanging from a tree limb.
Mounting the BirdCam

Scenario #3 – Mount with Standard Camera Tripod
The bottom of the BirdCam features a standard female tripod thread (size: \(\frac{1}{4} – 20\)). This enables the BirdCam to work with the vast majority of standard camera tripods. Camera tripods offer great stability and adjustability, so they are a great option to use with the BirdCam. (Note: Most tripods are NOT weatherproof.)

Shooting through Glass Windows
A tripod is a great option for users who want to setup the BirdCam indoors, aimed out of a window. However, the BirdCam’s infrared sensor can not detect bird activity through a pane of glass. If you plan to set up the BirdCam this way, use the TIMELAPSE mode to take photos or videos at a specified interval. This can result in more empty images, especially if feeder traffic is light. Alternatively, you can use the optional remote control accessory.
Mounting the BirdCam

Scenario #4 – Using the BirdCam Bracket
(optional accessory)
Wingscapes has designed an accessory bracket that makes it easy to mount a BirdCam on any round feeder pole with a diameter of ½” to 1½”.

For more information about this accessory, contact your local Wingscapes dealer or visit www.wingscapes.com
MODE Menu

This Mode menu allows you to move between the BirdCam’s three operating modes (AUTO, MANUAL, and TIMELAPSE) and the SETUP menu.

Enter the MODE menu:
At any time, press MODE to enter the MODE menu.

Navigate the MODE menu:
To navigate between the three operating modes (AUTO, MANUAL, and TIMELAPSE) and the SETUP menu, press either the MODE, +, or - button.

Enter your selection:
From the Mode menu, you can press the ► button to activate a selection.

NOTE: In the MODE menu, if no button is pressed within 30 seconds, the BirdCam will enter whichever selection is displayed.
Mode Menu

At any of the above screens, press > to enter your selection.
SETUP Menu

The SETUP offers a range of settings which allow you to customize how the BirdCam operates. You can control the number of images taken, infrared sensitivity, photo resolution, and other options that will optimize the BirdCam in different conditions.

REMEMBER: At any time, you can reset the BirdCam to its default, factory settings by scrolling to RESET TO EASY? in the SETUP menu and selecting EASY - PHOTO.

Using the SETUP Menu

Enter the SETUP menu:
From the MODE menu, press the +, -, or MODE button until the display reads: < ENTER SETUP >. Press either < or > to enter the SETUP menu.
Navigating through the settings:
To navigate between the different settings, use the < and > buttons.

Change values of a setting:
To change the values in a given setting, use the + and – buttons.

Save your selection:
Once you have selected a certain value in a setting, pressing either the < or > button will save that value.

Exit the SETUP menu:
Press the MODE button at any time to exit the SETUP menu and return to the MODE menu.

NOTE: If the BirdCam is left in this mode without activity for more than 4 minutes it automatically goes to AUTO mode (which is initiated by the 30 second countdown)

SETUP Menu – Settings and Values Explained

RESET TO EASY?
This setting allows you to reset ALL settings to the factory default.
Three values are available in the RESET TO EASY? setting:
**SETUP Menu**

**NO** – Select to leave the SETUP menu settings alone.

**EASY PHOTO** – Select this value to reset all SETUP menu settings to the default values (as they were when the BirdCam left the factory). These settings will be suitable for the average user. For a chart showing the EASY PHOTO default values, see the table below.

**EASY VIDEO** – Select this value to reset all SETUP menu settings to the default values, but sets the BirdCam to take video instead of photos. These settings will be suitable for the average user, when videos are preferred. For a chart showing the EASY VIDEO values, see the table below.

### EASY PHOTO and EASY VIDEO Settings

<table>
<thead>
<tr>
<th>Setting</th>
<th>NO</th>
<th>EASY PHOTO</th>
<th>EASY VIDEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESET TO EASY?</td>
<td>No</td>
<td>EASY PHOTO</td>
<td>EASY VIDEO</td>
</tr>
<tr>
<td>PHOTO OR VIDEO?</td>
<td>saves current setting</td>
<td>Photo</td>
<td>Video</td>
</tr>
<tr>
<td>PHOTO QUALITY ¹</td>
<td>saves current setting</td>
<td>Medium</td>
<td>(see note 2)</td>
</tr>
<tr>
<td>DELAY</td>
<td>saves current setting</td>
<td>5 min</td>
<td>5 min</td>
</tr>
<tr>
<td>#PHOTOS/EVENT ²</td>
<td>saves current setting</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>#VIDEOS/EVENT ²</td>
<td>saves current setting</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>SENSITIVITY</td>
<td>saves current setting</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>IMPRINT INFO?</td>
<td>saves current setting</td>
<td>Yes - Keep</td>
<td>Yes - Keep</td>
</tr>
<tr>
<td>REMOTE CONTROL</td>
<td>saves current setting</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>ERASE IMAGES?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>TEST CAMERA?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

1. PHOTO QUALITY setting does not appear when PHOTO OR VIDEO is set to VIDEO
2. #PHOTOS/EVENT becomes #VIDEOS/EVENT when PHOTO OR VIDEO is set to VIDEO
SETUP Menu

PHOTO OR VIDEO?
Use this setting to control whether the BirdCam takes photos or 10-second videos.

PHOTO – Choose this value to take photos.
VIDEO – Choose this value to take videos.

PHOTO QUALITY
NOTE: This setting does NOT appear when VIDEO is selected in the PHOTO OR VIDEO? setting.

Use this setting to control the resolution of the digital photos taken by the BirdCam.
**LOW 640 x 480** – Use this value to take low-resolution images. These images consume the least amount of memory, enabling users to take the maximum number of images. They are suitable for viewing on a computer or TV screen, e-mailing, or printing small photos.

**MED 1328 x 996** – This value is the factory default and should be used to take medium-resolution images. These images consume less memory than HIGH resolution photos. They offer more than enough detail for viewing on computer and TV screens and are sufficient for photo prints up to 5”x7”.

**HIGH 2048 x 1536** – Use this value to take high-resolution images. These images consume more memory, but they offer enough detail for photo prints up to 8”x10.” Some will prefer to reduce these images on a computer before emailing. We recommend using a larger capacity SD card when taking video or high resolution pictures.

---

**Average Memory Capacity vs. Photo Resolution**

<table>
<thead>
<tr>
<th>Photo Quality</th>
<th>Included (onboard)</th>
<th>Optional SD Card 256MB</th>
<th>Optional SD Card 512MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW 640 x 480</td>
<td>339</td>
<td>2,993</td>
<td>5,995</td>
</tr>
<tr>
<td>MED 1328 x 996</td>
<td>92</td>
<td>812</td>
<td>1,624</td>
</tr>
<tr>
<td>HIGH 2048 x 1536</td>
<td>37</td>
<td>327</td>
<td>653</td>
</tr>
<tr>
<td>VIDEO CLIP</td>
<td>7</td>
<td>62</td>
<td>124</td>
</tr>
</tbody>
</table>

*Estimate of average capacity. Image size varies depending on image properties.*
SETUP Menu

**DELAY**

The BirdCam uses this setting to avoid taking too many images of one bird, depleting battery power quickly, and/or consuming memory capacity quickly.

In AUTO mode, use this setting to control how often the BirdCam looks for activity. When the BirdCam ‘wakes’ from a delay in AUTO mode, it will look for animal movement until either movement is detected or the photocell forces it into NIGHT mode.

In TIMELAPSE mode, use this setting to adjust the time interval between photos (or videos). When the BirdCam ‘wakes’ from a delay in TIMELAPSE mode, it will immediately take photos (or videos) and then re-enter a delay.

**Notes about DELAY:**

- **NO DELAY option** – This specialized option is intended for advanced users. It will drain batteries faster and possibly result in an increased number of empty images without birds.
- **Long delays settings** – Long delays (4HR, 6HR, DAILY) may not produce good results when used to photograph birds. These values are most appropriate for TIMELAPSE photography of weather, plants, or other subjects that change over time. The DAILY value activates the BirdCam 1.5 hours after dawn each morning.
### DELAY values:

<table>
<thead>
<tr>
<th>Delay</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO DELAY</td>
<td>30 MIN</td>
</tr>
<tr>
<td>30 SEC</td>
<td>45 MIN</td>
</tr>
<tr>
<td>1 MIN</td>
<td>1 HR</td>
</tr>
<tr>
<td>2 MIN</td>
<td>4 HR</td>
</tr>
<tr>
<td>5 MIN*</td>
<td>6 HR</td>
</tr>
<tr>
<td>10 MIN</td>
<td>DAILY</td>
</tr>
<tr>
<td>20 MIN</td>
<td></td>
</tr>
</tbody>
</table>

*5 MIN is the default setting*
SETUP Menu

#PHOTOS/EVENT and #VIDEOS/EVENT
This setting allows you to specify how many photos the BirdCam will take between each delay period. When the PHOTO OR VIDEO? setting is set to VIDEO, this setting becomes #VIDEOS/EVENT and the maximum value is reduced from 10 to 3 (see table below).

Recommendation: If you are getting too many images (or too many empty images), select and lower value for #PHOTOS/EVENT. If you want more images, select a higher value.

<table>
<thead>
<tr>
<th>#PHOTOS/EVENT values:</th>
<th>#VIDEOS/EVENT values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>01**</td>
</tr>
<tr>
<td>02</td>
<td>02</td>
</tr>
<tr>
<td>03*</td>
<td>03</td>
</tr>
<tr>
<td>04</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td></td>
</tr>
<tr>
<td>06</td>
<td></td>
</tr>
<tr>
<td>07</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*03 is default value for EASY PHOTO
**01 is default value for EASY VIDEO
More about #PHOTOS/EVENT and #VIDEOS/EVENT:

In AUTO mode, this setting specifies the maximum number of photos (or videos) the BirdCam can take between delay periods. Provided that it detects continuous motion, the BirdCam will take the maximum number of photos and then re-enter a delay period. However, if the BirdCam detects motion and takes at least one photo, but then fails to detect motion for 60 seconds, it will re-enter a delay without taking the maximum number of photos.

In TIMELAPSE mode, when a delay period ends, the BirdCam immediately takes the specified number of photos (or videos) and then re-enters another delay period.

SENSITIVITY

The SENSITIVITY setting controls the infrared sensor. Factors such as weather, bird species, distance to target, and feeder type affect how effective the BirdCam is at detecting bird movement while ignoring feeder movement. The SENSITIVITY setting enables you to compensate for these varying factors.
SETUP Menu

**LOW** – This value should be used when you are getting too many images using the MEDIUM value. This may happen when the BirdCam is mounted very close to its target or if many birds are flying behind the feeder without landing.

**MEDIUM** – This option is the default factory value and should be used in most cases. When you are trying a new mounting location, test results using this MEDIUM value and then adjust to HIGH or LOW accordingly.

**HIGH** – Use this setting if you think the BirdCam is not triggering often enough with the MEDIUM value selected. This value can be useful when the distance between BirdCam and target is farther than 5 feet or when you are trying to capture smaller birds.

**IMPRINT INFO?**
This setting allows you to imprint the time and date that a photo was taken, along with a camera name in a databar at the bottom of your photos. The databar does reduce the vertical dimensions of your photo image area slightly. There are three options for this setting.
**SETUP Menu**

**YES-KEEP** – This option is the default factory value and simplifies the SETUP menu. The imprint information that is currently programmed into the BirdCam will appear in a databar at the bottom of your photos. This selection allows you to bypass the time, date, and BirdCam name programming screens.

**YES-CHANGE** – Select this option and press ▶ to enter the time, date, and BirdCam name programming screens.

To change DATE, TIME, and CAMERA NAME:
1. Press + or - to display YES-CHANGE
2. Press ▶ to enter SETUP DATE/TIME
3. Press + and – to change values for day, month, year, hour, minute, and AM/PM
4. Press < and ▶ to move between day, month, year, hour, minute, and AM/PM
5. From SETUP DATE/TIME screen, press ▶ to enter the CAMERA NAME screen.
6. Press + and – to change characters in a given position in the camera name.
7. Press < and ▶ to move between character positions in the camera name.

**NO** – This option will not print a databar with time, date, and camera name on the bottom of your photos. This selection allows you to bypass the time, date, and BirdCam name programming screens.
REMOTE CONTROL
This setting controls whether the BirdCam can be controlled with an optional BirdCam remote control. There are two options for this setting.

**OFF** – This option is the default factory value. The optional BirdCam remote control will not work when NO is selected.

**ON** – This option tells the BirdCam to look for a signal from the optional BirdCam remote control. The BirdCam will consume batteries faster when YES is selected. Please refer to the instructions for the optional BirdCam remote control for more information about installing and using the remote.
**ERASE IMAGES?**
This setting allows users to permanently erase all photos and videos stored in the BirdCam’s memory.

**NO** – This option is the default factory value. Selecting this value will have no affect on the BirdCam.

**YES** – To permanently erase all photos and videos stored in the BirdCam’s memory, select YES and press ↓. When DONE is displayed, the memory has been erased.

- **SD Card installed** – This option will only erase the SD card. It will not affect images stored in the BirdCam’s internal memory.

- **SD Card NOT installed** – This option will erase the BirdCam’s internal memory.
SETUP Menu

TEST CAMERA?

This option allows you to run a diagnostic test on the BirdCam. It is used to check the BirdCam’s functionality and verify that it is working properly. During this test, important subsystems are tested. This setting has two options:

**NO** – This option is the default factory value. Selecting this value will have no effect on the BirdCam.

**YES** – Select this option and press ▶ to run a diagnostic test. When you see the message WAVE HAND NOW wave your hand horizontally about 12 inches from the BirdCam’s infrared sensor. When you see the message TEST IN PROGRESS, stop waving and wait for results. For an explanation of test results, see the Troubleshooting section.
About the Laser Aiming Device
The BirdCam’s laser aiming device will help aim the BirdCam accurately. When turned ON, the laser projects a red dot where the center of the image will be.

IMPORTANT: Looking into the laser may be hazardous to the eyes. Do not stare into beam or aim at other people. Read the warning label on BirdCam before operating laser.

To operate the laser aiming device
1. With the BirdCam door open, use the MODE button to display < ENTER SETUP > and press ▼ to enter the SETUP menu. (RESET TO EASY? will display).
2. With the BirdCam pointed toward its target (and away from people), press the LASER AIM button. This will activate the laser aim while you adjust the positioning on the BirdCam.
3. To turn off the laser and re-enter SETUP mode, press the LASER AIM button again. If the laser is not turned off manually, it will time-out after 90 seconds.
AUTO Mode

In AUTO mode, the BirdCam uses an infrared sensor to detect bird movement, and then automatically takes either a photo or a video clip (depending on settings chosen in the SETUP menu).

NOTE: A combination of heat and motion are required to trigger this infrared sensor. The BirdCam’s infrared sensor can not detect bird activity through a pane of glass. If you plan to shoot through a window, use the TIMELAPSE mode or optional remote control.

Enter AUTO mode:
From the MODE menu, press the +, -, or MODE button until the display reads: START AUTO >. Press ▶ to enter AUTO mode. The BirdCam will countdown for 30 seconds before watching for birds. (This gives you time to shut the door and walk away.)

Exit AUTO mode:
Press the MODE button at any time to exit AUTO mode and return to the MODE menu.

To see which SETUP menu settings take affect in AUTO mode, see the chart on page XX
MANUAL Mode

In MANUAL mode, the BirdCam operates like a regular digital camera. When the SHUTTER button is pressed, the BirdCam takes either a photo or a video clip (depending on settings chosen in the SETUP menu).

NOTE: The motion-sensor is NOT active in the MANUAL mode.

Enter MANUAL mode:
From the MODE menu, press the +, -, or MODE button until the display reads: START MANUAL >. Press ▶ to enter MANUAL mode.

Exit MANUAL mode:
Press the MODE button at any time to exit MANUAL mode and return to the MODE menu.

To see which SETUP menu settings take affect in MANUAL mode, see the chart on page XX
TIMELAPSE Mode

In TIMELAPSE mode, the BirdCam takes photos or videos at a specific time interval that you set.

NOTE: The motion-sensor is NOT active in the TIMELAPSE mode.

Enter TIMELAPSE mode:
From the MODE menu, press the +, -, or MODE button until the display reads: START TIMELAPSE >. Press › to enter TIMELAPSE mode. The BirdCam will countdown for 30 seconds before entering TIMELAPSE mode. (This gives you time to shut the door and walk away.)

Exit TIMELAPSE mode:
Press the MODE button at any time to exit TIMELAPSE mode and return to the MODE menu.

To see which SETUP menu settings take affect in TIMELAPSE mode, see the chart on page XX
### Which Settings are Active in which Mode?

<table>
<thead>
<tr>
<th>Setting</th>
<th>AUTO</th>
<th>MANUAL</th>
<th>TIMELAPSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESET TO EASY?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>PHOTO OR VIDEO?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>PHOTO QUALITY(^1)</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>DELAY</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td>#PHOTOS/EVENT(^2)</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td>SENSITIVITY</td>
<td>yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>IMPRINT INFO?</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>REMOTE CONTROL</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>ERASE IMAGES?</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TEST CAMERA?</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1. PHOTO QUALITY setting does not appear when PHOTO OR VIDEO? is set to VIDEO
2. #PHOTOS/EVENT becomes #VIDEOS/EVENT when PHOTO OR VIDEO? is set to VIDEO
Accessing Photos and Videos

View Images on a TV
When connected to a TV, the BirdCam controls can be used to scroll through photos and videos. This method will work using the BirdCam’s internal memory or with an optional SD card inserted.

1. Connect the supplied A/V cable to the TV OUT jack on the BirdCam.
2. Connect the opposite end of the supplied A/V cable to a VIDEO IN jack on your TV.
3. Turn the BirdCam ON and enter the SETUP MENU.
4. Use the + and - buttons to scroll through photos and videos.

View Images on a Computer — Using Supplied USB Cable
When connected via USB cable, the vast majority of computers will recognize the BirdCam as a new drive. This method will work using the BirdCam’s internal memory or with an optional SD card inserted.
Accessing Photos and Videos

1. Turn the BirdCam ON.
2. Connect the smaller end of the supplied USB cable to the USB OUT jack on the BirdCam.
3. Connect the larger end of the supplied USB cable to a USB jack on the computer.
4. On the BirdCam, enter the SETUP menu.
5. Your computer should recognize your BirdCam as a new drive.
   a. WINDOWS (Windows 2000/ME/XP/Vista required): BirdCam memory should appear as a new drive labeled “Removable Disk” under My Computer
   b. MAC: BirdCam memory should appear as new drive in Finder.

Viewing Images on a Computer — Using Optional SD Memory Card and Reader

Using an optional SD memory card not only allows you to expand your BirdCam’s memory, but it allows you to leave your BirdCam mounted outdoors while accessing images from the SD memory card.

IMPORTANT: Always turn BirdCam OFF when inserting or removing a memory card. (See other notes regarding SD memory cards under “Memory Capacity & Storage” in section “Getting to Know the BirdCam”

1. Turn BirdCam OFF.
2. Eject SD memory card from BirdCam.
3. Use a memory card reader on your computer to access images. Refer to your card reader’s documentation for specific instructions.
Troubleshooting

Contact Us
If you are unable to find answers to your questions in this section, please contact Wingscapes Customer Support:

WINGSCAPES
150 Industrial Road
Alabaster, AL 35007
Phone: 888.811.WING (9464)
Fax: 205.408.6157
support@wingscapes.com
www.wingscapes.com/support

Solutions to Common Problems
1. BirdCam takes too few photos (or videos) in AUTO mode.
   Suggestions:
   • Check to make sure that the BirdCam is aimed properly and nothing is between your target and the infrared sensor.
   • DECREASE the DELAY setting.
   • INCREASE the #PHOTOS/EVENT setting.
   • INCREASE the SENSITIVITY setting.
   • DECREASE distance between BirdCam and your target.

2. BirdCam takes too many photos (or videos) in AUTO mode.
   Suggestions:
   • DECREASE the #PHOTOS/EVENT setting.
   • INCREASE the DELAY setting.
   • DECREASE the SENSITIVITY setting.
3. BirdCam takes an unusually high number of empty images (without birds) in AUTO mode.

Suggestions:
Some empty images are inevitable. Empty images most commonly result from birds flying past the BirdCam without landing or, in rare cases, movement of the feeder itself. If the ratio of empty images to images with birds is unusually high, try the following...

- DECREASE the SENSITIVITY setting.
- DECREASE the #PHOTOS/EVENT setting.
- Position the BirdCam to minimize open area behind the target (eg - aim at feeder against a wall or seed on the ground). This should reduce the number of ‘fly-by’ triggers.

4. Photos or Videos are too dark or too light.

Suggestion:
As with any automatic camera, the BirdCam’s image quality depends on many variables, such as the source and intensity of light. During dawn and dusk, it is normal for the BirdCam to take some dark images.

*Ideal light conditions are shade or indirect sunlight.*

If your images are poorly exposed in all conditions, please contact customer support.
Troubleshooting

Diagnostic Test

Running a diagnostic test is an option in the SETUP menu. It is used to check the BirdCam functionality and verify that it is working properly. During this test, important subsystems are tested.

Run the Diagnostic Test

1. In SETUP menu, press the < or > button until TEST CAMERA? appears.
2. Press the + or – button until YES appears.
3. Press < or > button to activate your selection.
4. When you see the message WAVE HAND NOW wave your hand about 12 inches from the BirdCam’s infrared sensor. When you see the message TEST IN PROGRESS stop waving.

Diagnostic Test Messages

After the diagnostic test is complete, a message indicating the status of the BirdCam will display.

If no problems are detected, ALL SYSTEMS OK will display for 5 seconds.

If a problem is detected, a 6-digit error code will display for 10 seconds, indicating the status of the BirdCam system.
Troubleshooting

Error Code: X X X X X

Battery Test
- 0 = Battery Passed
- 1 = Battery O.V. or Battery Low

IR Sensor Test
- 0 = IR Sensor Passed
- 3 = IR Sensor Failed

Cam Mod Test
- 0 = Cam Mod Passed
- 4 = Cam Mod Failed

Clock Test
- 0 = Clock Passed
- 9 = Clock Failed

Memory Test
- 0 = Memory OK or No SD Card MemOK
- 5 = Memory Full
- 6 = SD Card Locked
- 7 = SD Card Damaged
- 8 = Comms Error
BirdCam Accessories

For more information about BirdCam Accessories or to find a dealer near you, please contact Wingscapes:

WINGSCAPES
150 Industrial Road
Alabaster, AL 35007
Phone: 888.811.WING (9464)
Fax: 205.408.6157
support@wingscapes.com
www.wingscapes.com/support

BirdCam Bracket
Product # WSBR01
This accessory bracket makes it easy to mount the BirdCam to most standard bird feeder poles.

BirdCam Remote Control
Product # WSRC01
The BirdCam can be controlled remotely with an optional accessory, creatively named the “BirdCam Remote Control.”

NOTE: Some BirdCam’s are sold with the Remote Control system included.
BirdCam Remote Control - continued

By pressing either the PHOTO or VIDEO button on this remote, a user can force the camera to take a photo or video at any time. The remote works in AUTO, MANUAL, and TIMELAPSE modes and does not interrupt the BirdCam’s operation.

This remote system can only be used with the Wingscapes BirdCam.

Remote Control Instructions:

1. With BirdCam turned OFF, remove dust gaurd from plug labeled “Remote Control Card” and insert the included remote chip. Replace dust cover after installing chip.
2. Turn the BirdCam ON and activate the Remote Control by selecting REMOTE CONTROL “ON” in the BirdCam Setup Menu.
   Tip: To maximize BirdCam battery life, turn this setting “OFF” when you are not planning to use the Remote Control.
3. To take a photo or video, press and hold the appropriate button on the remote fob for 2 seconds.

IMPORTANT:
This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.
Warranty

This product has been thoroughly tested and inspected before shipment. It is guaranteed from defects in material and workmanship from the date of purchase for 1 year. Under this limited guarantee, we agree to replace or repair free of charge any part or parts, which have been found to be defective in original material or workmanship. Should you require in-warranty service, call our Customer Support Department. If your problem cannot be addressed over the telephone, we may need you to send us your defective product plus proof of purchase.

Wingscapes Customer Support -

WINGSCAPES
150 Industrial Road
Alabaster, AL 35007

Phone: 888.811.WING (9464)
Fax: 205.408.6157
support@wingscapes.com
www.wingscapes.com/support
Additional Information

The following information relates to the BirdCam’s laser aiming device.

Class II Laser Product
Wavelength: 650 nm
Maximum Output: < 1 mW

This product complies with the applicable requirements of 21 CFR 1040.10 and 1040.11

Caution: Looking into the laser beam may be hazardous to the eyes. Do not stare into the beam or direct it toward other people.

Caution: Use of controls or adjustments or performance of procedures other than those specified herein, may result in hazardous radiation exposure.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.
Additional Information

This product label can be found inside the battery compartment.

This yellow, laser-warning label can be found inside the door, on the face of

Customer Service

WINGSCAPES
150 Industrial Road
Alabaster, AL 35007
WWW.WINGSCAPES.COM
1-888-811-WING (9464)

Model Number: W5CA01
Serial Number:

CK70300001

Manufactured by:
Wingscapes, a division of Plastics Research and Development Corporation.

This product is covered by one or more of the following US patents:
6,753,587, 6,768,868,
6,834,162 and other pending patents.

This product complies with applicable requirements of 21 CFR 1040.10 and 1040.11.

No user serviceable parts inside.

This device complies with part 15 of the FCC rules. Operation is subject to the following two conditions:
(1) This device may not cause harmful interference, and
(2) this device must accept any interference received, including interference that may cause undesired operation.
Power Up
When you power the unit on, you will see “Refresh Camera” on the LCD. At that time, the camera will power up for a few seconds to make sure that the flash is charged. Once the camera is refreshed, then the LCD will display “Ready” for a few seconds and then the LCD will power off. If everything is set as you like, then you are done and the unit is ready to start taking pictures or ready for walk test (depending on whether you have it set to start in walk test mode) when the motion switch is turned on.

Motion Switch:
In the OFF position, this switch allows you to open and close the lid and change settings as you desire without activating the unit. Place the switch in the ON position to turn motion activation on. This is where you need the switch set for normal operation and test mode.

User Interface:
Before entering Setup, make sure that the Motion switch is off. To enter setup, press and hold the “Mode” Button until you see text on the LCD. The top line of the LCD is the feature you are changing, and the bottom line is the setting that you want the feature set to. To change the top line from one feature to the next, press the “Mode” button, to change the feature to a different setting, press the “Set” button. To exit setup, press the mode button until you see “Set To SaveExit”. Press “Set” here and your settings will be saved, and you will exit the setup mode and be back in normal operating mode, ready to take pictures. Don’t forget to turn the “Motion Kill” switch back on.

Delay Feature
This feature determines the amount of time that has to pass before the unit will take a picture after a picture has already been taken. For example: If the time is set to 10 minutes and an animal triggers the unit, even though the animal may still be moving in front of the unit, it will not trigger again for 10 minutes. You will find that the Snapshot Sniper system has a separate delay for day and night. This is very useful for a few reasons. One is that for maximum speed, you can set it to 5 seconds in the daytime and then set it longer for night time to allow for the camera flash to charge. The delay settings are especially useful on a feeder setup, so that one animal won’t use all of the memory card. If you have a problem with birds taking up multiple pictures during the day, now you can set the delay time longer and still keep it short at night, or you have a coon problem at night, then you can set the night delay longer, it’s up to you. The delay times as follows:
- 5S, 10S, 15S, 20S, 1M, 2M, 5M and 10M delays

Pictures Per Event Mode
With this mode, you can select 1 to 5 pictures per event. After motion is detected and a picture is taken, the unit will continue taking up to 5 pictures (depending on what you have it set on) approximately 5 seconds apart in the daytime and approximately 10 seconds apart at night; regardless of whether there is still motion or not. Once the last picture has been taken then the unit starts the delay between pictures again based on the Delay setting. This setting can be useful to get different views of the same animal.

Activity mode
Activity mode will allow the sensor to trigger the camera about every 4 seconds. At night, depending on the amount of light outside and how close the animal is, the flash most likely won’t be recharged enough in
4 seconds and will be ready again if motion is still detected at 8 or 12 seconds. In this mode, the camera shuts off after 20 seconds of no motion, or after approximately 45-60 seconds, even if there is still motion so that one animal can't keep it going indefinitely.

**Sensitivity Feature**
This feature controls the distance at which the unit can be activated. The options are:

- Extra High
- High
- Medium
- Low

It is recommended to start with a medium setting and see if you get the distance that you need by using the “WalkTest” feature (described later). In certain conditions such as areas of heavy vegetation, it may be necessary to set the sensitivity feature to a lower setting if you are getting many “false” triggers.

**Day/Night Feature**
This feature has three options:

- 24 Hour (Unit is always active)
- Day Only (Unit will be active only in the day time).
- Dark Only (Unit will be active only in the night time).

**Walk Test Feature**
With walk test on (and the motion switch on), every time the unit senses motion, the LED will blink. Note: It will take a second or two for the sensor to reset after sensing motion before it can be triggered again. If the unit doesn’t detect motion for 1 minute, walk test will automatically turn off and the unit will be ready to take pictures. By doing this, you can turn walk test on, mount your setup and lock it up. Then after you are through with the walk-test, you can just leave it and let it turn off itself. You should use this feature each time you set your system up, to ensure it will detect motion where you need it to.

**Start Walk**
With this setting on, the board will automatically start in walk test mode each time you turn it on. With this option off, it will start in camera mode.

**Troubleshooting:**
- **How come I have pictures with no animals in them?**
  Listed below are common conditions that can cause this:
  1. The unit is in double picture mode, and the animal left the area before the second picture was taken.
  2. The animal was moving fast enough to be out of the camera’s view before the picture was taken.
  3. The wind is moving limbs or other vegetation enough that the trigger unit is activated. (Clear out the vegetation or move the unit to a clear area. Reducing sensitivity will also help.)
  4. In high temperatures, heat wave can cause false triggers, reduce the sensitivity.
  5. The 9-volt battery that powers the trigger unit is low. Replace the battery. If this is the case, the unit will take a picture in intervals of the delay mode. For example, if the unit is set with a 20 second delay), then the unit will take a pictures every 20 seconds.

- **Why isn’t the sensor picking up motion at long distances?**
  1. The sensitivity setting may be turned down.
  2. The camera is pointing too high or too low to detect movement. You can correct this by placing a twig behind the unit to tilt it up or down. This can really make a BIG difference.
  3. High temperatures. The detection distance will decrease as the outside temperature rises.

Listed below is what you can expect from a Snapshot Sniper Digital Scouting System (All temps are in Fahrenheit)

**At approximately 65 degrees or less:**
- High Sensitivity Setting: Approximately 80-90 feet (This system has detected motion at well over 120 feet in below freezing temperatures.)
- Low Sensitivity Setting: Approximately 30-40 feet.

85 degrees and up:
As temperatures increase close to the body temperature of the animal, detection range is dramatically reduced. A high sensitivity setting is needed in these conditions. When temperatures start pushing 100 degrees or more, detection range may be reduced to 10-20 feet.

Tips:
- Do not face the camera directly into the sun... this can damage the sensor in the camera, and can occasionally cause false triggers.
- Do not place the camera in direct sunlight. On sunny summer days, the temperature inside of the enclosure can become much higher than the outside temperature and cause damage to the camera.
- Clear out any limbs or vegetation in front of the camera to prevent false triggers.
- Experiment with different feeds and scents to draw animals to your camera.
- Keep the glass in front of the camera lens clean for better pictures. When cleaning the front side of the glass, apply pressure to the back side to prevent pushing the glass loose from the enclosure.
- Don’t forget to send in your best pictures and we’ll put them on our website. 
Pictures@snapshotsniper.com
Rugged Network Camera offers High Definition Resolution at Streaming Video Speeds

Built on StarDot’s proven NetCam technology, the NetCam XL series of network cameras combines high resolution imaging with streaming video speeds, all in a rugged all-temperature package. Features include compatibility with both standard DC auto iris lenses and motorized zoom lenses, sophisticated integrated video motion detection and the ability to attach a weather station and display the current weather data on the live image.

For more information, call us at 1-888-STARDOT (888-782-7368) or visit us at www.stardot-tech.com
Excellent Digital Image Quality up to 2048x1536

NetCam XL Specifications

Imaging
- NetCam XL = Sharp 1/3” CCD sensor, 640x480 RGB, Frame Transfer, 30 FPS
- NetCam XL 1.3 MP = Sony 1/2” CCD sensor, 1344x1024 RGB, Frame Transfer, 5 FPS
- NetCam XL 3 MP = Micron 1/2” CMOS sensor, 2048x1536 RGB, Frame Transfer, 225 FPS
- Exposure range: 1/100,000 second - 1.3 seconds
- Auto/manual exposure, auto/manual color balance, sharpening, auto/manual haze
- Contrast enhancement, gamma correction
- Customizable date/time/text overlay
- Image format: JPEG, adjustable quality / filesize
- Lens: 8mm C-Mount with manual iris and focus rings
- Lens Mount: Industry standard CS-Mount, includes C-Mount adapter

Operating System / CPU
- uClinux operating system
- Motorola Coldfire CPU
- Built-in web server, telnet server and FTP client
- Supported protocols: TCP/IP, HTTP, FTP, ARP, Telnet, Daytime, X/Y/Zmodem
- 32MB DRAM, 4MB Flash Memory
- Security: Password-protected user accounts for viewing and configuring NetCam XL

Connectivity
- 1 x 10/100-baseT Ethernet, RJ-45
- 1 x DC Auto Iris Connector
- 1 x Motorized Zoom Lens Connector
- 2 x RS-232 Serial Ports, DB9 Male, up to 115.2kb
- 4 x digital alarm inputs or 4 x 5V swing output pins
- 1 x fully isolated relay rated at 28VDC 2A or 125VDC 0.5A

Physical
- Dimensions: 3.25” W (82.5mm) x 2.20” H (55.9mm) x 6.56” L (166.6mm)
  Included lens adds 1.1” (27.9mm) to length, Included (removable) 1/4" tripod mount adds 0.4” (10.1mm) to height
- Weight: 19.5 ounces (553 grams)
- Case: Aluminum clam shell body, argentan alloy front cover
- Mounting: Universal 1/4” tripod mount, top or bottom of camera
- Operating temperature range: -40° - +120° F (-40° - +48° C)
- Power Requirements: 6VDC-15VDC, 500mA @ 12V, 12VDC power supply included
- EMI Approval: FCC, Class A

Two Serial Ports - Connect NetCam XL to analog or wireless modem, or accessories like weather station & automation controller

Power Jack - Includes single cable for both power and data -- great for rooftop, ceiling and remote installations

Aux and I/O Ports - Connect to alarm system and motorized zoom lens

Built-in 10/100 Ethernet Port
- Plug NetCam directly to LAN, Cable Modem or DSL network

Contents Include:
- NetCam XL Camera with Integrated Web Server
- 8mm C-Mount Lens with Manual Iris/Focus
- 50 ft. Combination Power/Network Cable
- Power Supply (12VDC, 1A)
- Indoor Wall Mount
- Dial-Out Package Includes External Modem
- Easy-to-Use StarDot Tools Setup Software
Follow the steps in this Quick Start Guide to configure a HOBO U30 Station with Remote Communication.

**NOTE:** This guide does not cover the following: configuration of the Analog Sensor Port or TRMS modules, configuring a static IP address.

For more information see the *HOBO U30 Station/Remote Communication User Guide*, available as a printable file from the Onset web Site at: www.onsetcomp.com/wi-fi or www.onsetcomp.com/rms-outdoor

## Initial HOBOlink Setup
For more information on HOBOlink, see the *HOBOlink Help available in the HOBOlink application at hobolink.com*.

### Step 1 - Setup HOBOlink Account
If you have not already done so, set up a HOBOlink™ account. Go to https://www.hobolink.com and follow the instructions to create and activate a user account.

### Step 2 - Register the HOBO U30 Station
Click the *Register a Device* link and follow the instructions on the screen. Give the device a nickname, then enter both the serial number (SN) and Device Key (located on a label inside the HOBO U30 Station). Click the name of the device to go to the *Device* window and configure the device.

### Step 3 - Change Time Zone (if necessary)
Click *Device Configuration* in the Task Bar.

### Step 4 - Configure the Logging Interval
a. Click *Launch Configuration*.
b. Enter a *Launch Description*. This will also be used as the filename for the data readouts.
c. Select a *Logging Interval*. For an initial test, configure a fast logging interval.

### Step 5 - Configure the Connection Interval
a. Click *Readout Configuration*.

b. Enter a *Connection Interval* (how frequently the HOBO U30 Station will connect to HOBOlink). For an initial test, configure a fast *Connection Interval*.

**NOTE:** For the U30/GSM, the Connection Interval is limited by the Fastest Connection Allowed by your Communication Plan. For testing, you can bypass your GSM Communication Plan restrictions by manually connecting to HOBOlink using HOBOware (direct connection using a USB cable). From the main menu select *Status*, and then click the *Contact HOBOlink* button.
**Initial Hardware Setup**

**IMPORTANT:** Your Communication Plan will be activated one week after the unit is shipped and you will begin paying for HOBOlink access, regardless of whether or not you have registered and activated your unit.

**IMPORTANT:** Always plug-in the battery first, before you plug-in any solar panel or power supply connector. When disconnecting power, always un-plug any solar panel or power supply connector first, then un-plug the battery.

**Step 1 - Install Mounting Plates**
Screw the mounting plates onto the back of the HOBO U30 Station case using a Phillips-head screwdriver. Be careful to orient the plates so that the screw heads are sunk into the screw holes.

**Step 2 - Plug in Smart Sensors**
Insert the Smart Sensor cables through the cable access opening in the bottom of HOBO U30 Station and plug them into the Smart Sensor jacks.

If you are using the Smart Sensor Expander Board, you should install cables in those slots first. You must first remove the Secondary Cable Slot cover. See the *U30 Station/Remote Communication User Guide* for details.

**Step 3 (Wi-Fi Only) - Connect the U30 to a Computer**
Before you connect the battery, you must connect the U30/Wi-Fi Station to a computer using a USB cable supplied by Onset.

**Step 4 - Connect the Battery**
Power up the HOBO U30 Station by plugging in the built-in battery cable into the battery connector.

**Step 5 - Configure Analog Sensor Port or TRMS Module (Optional)**
If you are using the Analog Sensor Port or TRMS modules, use HOBOware now to perform that configuration. See the *HOBO U30 Station/Remote Communication User Guide* for details.

**Next Task**
- U30/GSM - go to *Final HOBOlink Setup and Test.*
- U30/Wi-Fi - go to *Configuring WLAN Settings for the U30/Wi-Fi.*
- U30/Ethernet - if you have a static IP address, see *Configuring a Static IP Address in the U30/RC User Guide.* Otherwise go to *Final HOBOlink Setup and Test* in this Quick Start Guide.
Configuring WLAN Setting for the U30/Wi-Fi

NOTE: If you are not familiar with network configuration, consult with your Network Administrator or IT Department.

If you have a HOBO U30/Wi-Fi, you must configure the WLAN settings each time you move the HOBO U30/Wi-Fi Station to a different network, using Onset’s HOBO Netsetup utility.

Static IP Addresses: If you have a U30/Wi-Fi or U30/Ethernet and your network uses static IP addresses rather than DHCP, you must configure a static IP Address. See the HOBO U30 Station/RC User Guide for details.

Step 1 - Download HOBO NetSetup (Supported for PC only)
Before you Begin: the HOBO NetSetup utility requires Microsoft .NET Framework (version 2.0 or above) installed. To determine if you have this installed on your PC, go to Start > Control Panel > Add or Remove Programs and see if it is in the list of currently installed programs.

Onset’s HOBO Netsetup utility and Microsoft .NET Framework can be downloaded from the following location:
http://www.onsetcomp.com/support/software_utilities#downloads-1

Step 2 - Launch HOBO NetSetup.
Default configuration information will scroll by as the program launches and then the welcome screen will appear.

Step 3 - Click Begin. The Change Setup screen appears:

Step 4 - Access WLAN Setup
IMPORTANT: DO NOT select option 7 “Defaults” The U30/Wi-Fi has been preconfigured by Onset Computer. Selecting option 7 from the setup menu will reset the unit to factory defaults, which will require extensive reconfiguration.
Type 4 and press Enter to access the WLAN setup.

For a typical setup, you only need to enter the Network Name, the Security Suite and a Device Key or Password. You can accept the defaults for other parameters.

Step 5 - Follow the prompts to configure WLAN.
Default values are shown in parenthesis. To accept the default, hit Enter. For more information on options, see WLAN Options in the HOBO U30 Station/Remote Communication User Guide.

Step 6 - Save and Exit
When finished, save the new configuration by typing 9 and pressing Enter. “Parameters stored....” will appear on the screen.

Step 7 - Remove the USB cable from the U30 Station

Step 8 - Cycle power on the U30 Station (disconnect and reconnect the battery)
The U30 Station will connect to HOBOlink at the next Connection Interval.
Go to Final HOBOlink Setup and Test.
Final HOBOlink Setup and Test

Step 1 - Log into HOBOlink

Step 2 - Perform additional HOBOlink configuration if required
   (Label Sensors, Configure Alarms)

NOTE: If you wish to start a new launch once you set up the HOBO U30 Station in the field, be sure to select Force Relaunch on Next Connection in Launch Configuration.

Step 3 - Verify Proper Operation
   Make sure the data for all the Smart Sensors appears as expected in the Latest Conditions panel. Verify that graphs appear to be correct. Let the HOBO U30 Station connect 2 or 3 times and verify the data after each connection.

Step 4 - Configure Field Values
   When you are satisfied that the HOBO U30 Station and HOBOlink are working properly, change your Logging Interval and Connection Interval to your desired settings for deployment.

IMPORTANT: For the U30/GSM, make sure your Connection Interval is set to the Average Connection Interval for your Communications Plan or slower.

Step 5 - Repack the Logger and Sensors for Transit
   Onset strongly recommends that you use the original packaging when possible because it is custom-designed to protect the weather station and its components.

Important: If you are not deploying the system immediately, disconnect the battery to preserve battery power and reduce cellular transmission costs.

For instructions on Installing the HOBO U30 Station in the Field, see the HOBO U30 Station/Remote Communication User Guide.

Support
For support, please contact the company that you bought the products from:
Onset Computer Corporation or an Onset Authorized Dealer.
1-800-LOGGERS (1-800-564-4377) or 508-759-9500
8 AM to 5 PM ET, Monday through Friday Fax: 508-759-9100

Contact Information
Onset Computer Corporation 470 MacArthur Blvd  Bourne, MA 02532
Mailing Address: PO Box 3450  Pocasset, MA 02559-3450
email: loggerhelp@onsetcomp.com Main Onset website: www.onsetcomp.com

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Soil Moisture Smart Sensors (S-SMx-M005)

The Soil Moisture smart sensor is used for measuring soil water content and is designed to work with smart sensor-compatible HOBO® data loggers. It combines the innovative ECH2O® Dielectric Aquameter probe, from Decagon Devices, Inc. with Onset’s smart sensor technology. All sensor parameters are stored inside the smart sensor adapter, which automatically communicates configuration information to the logger without any programming or extensive user setup.

### Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>S-SMA-M005</th>
<th>S-SMB-M005</th>
<th>S-SMC-M005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Range</td>
<td>In soil: 0 to 0.405 m³/m³ volumetric water content) See Note 1.</td>
<td>In soil: 0 to 0.450 m³/m³ volumetric water content) See Note 1.</td>
<td>In soil: 0 to 0.550 m³/m³ volumetric water content) See Note 1.</td>
</tr>
<tr>
<td>Extended range</td>
<td>±0.29 to 1.4475 m³/m³ (full scale)</td>
<td>±0.376 to 1.964 m³/m³ (full scale)</td>
<td>±0.401 to 2.574 m³/m³ (full scale)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.041 m³/m³ (±4%) typical 0 to +50°C (+32° to +122°F) for medium textured soils up to 1 ds/m.</td>
<td>±0.041 m³/m³ (±4%) typical 0 to +50°C (+32° to +122°F) for medium textured soils up to 1 ds/m.</td>
<td>±0.031 m³/m³ (±3%) typical 0 to +50°C (+32° to +122°F) for mineral soils up to 8 ds/m.</td>
</tr>
<tr>
<td></td>
<td>±0.020 m³/m³ (±2%) with soil specific calibration See Note 2.</td>
<td>±0.020 m³/m³ (±2%) with soil specific calibration See Note 2.</td>
<td>±0.020 m³/m³ (±2%) with soil specific calibration See Note 3.</td>
</tr>
<tr>
<td>Resolution</td>
<td>±0.0004 m³/m³ (±0.04%)</td>
<td>±0.0006 m³/m³ (±0.06%)</td>
<td>±0.0007 m³/m³ (±0.07%)</td>
</tr>
<tr>
<td>Soil Probe Dimensions</td>
<td>254 x 32 x 1.0 mm (10 x 1.25 x 0.04 in.)</td>
<td>152 x 32 x 1.0 mm (6 x 1.25 x 0.04 in.)</td>
<td>89 x 15 x 1.5 mm (3.5 x 0.62 x 0.06 in.)</td>
</tr>
<tr>
<td>Weight</td>
<td>200 grams (7.0 oz)</td>
<td>190 grams (6.7 oz)</td>
<td>180 grams (6.3 oz)</td>
</tr>
<tr>
<td>Decagon ECH2O Probe Part No.</td>
<td>EC-20</td>
<td>EC-10</td>
<td>EC-5</td>
</tr>
</tbody>
</table>

### Specifications All models

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Operating Temperature</td>
<td>0°C to +50°C (+32° to +122°F). While the sensor probe and cable can safely operate at below-freezing temperatures (to -40°C/F) and up to +75°C (+167°F), the soil moisture data collected at these extreme temperatures is outside of the sensor’s accurate measurement range.</td>
</tr>
<tr>
<td>Bits per Sample</td>
<td>12</td>
</tr>
<tr>
<td>Number of Data Channels</td>
<td>1</td>
</tr>
<tr>
<td>Measurement Averaging Option</td>
<td>No</td>
</tr>
<tr>
<td>Cable Length Available</td>
<td>5 m (16 ft)</td>
</tr>
<tr>
<td>Length of Smart Sensor Network Cable</td>
<td>0.5 m (1.6 ft)</td>
</tr>
<tr>
<td>CE</td>
<td>The CE Marking identifies this product as complying with all relevant directives of the European Union (EU).</td>
</tr>
</tbody>
</table>

*A single smart sensor-compatible HOBO logger can accommodate 15 data channels and up to 100 m (328 ft) of smart sensor cable (the digital communications portion of the sensor cables).

Note 1: The sensor is capable of providing readings outside the standard volumetric water content range. This is helpful in diagnosing sensor operation and installation. See the Operation section below for more details.
Soil Moisture Smart Sensor

Note 2: This is a system level accuracy specification and is comprised of the ECH2O probe’s accuracy of ±0.04 m³/m³ typical (±0.02 m³/m³ soil specific) plus the smart sensor adapter accuracy of ±0.001 m³/m³ at +25°C (+77°F). There are additional temperature accuracy deviations of ±0.003 m³/m³ / °C maximum for the ECH2O probe across operating temperature environment, typical <0.001 m³/m³ / °C. (The temperature dependence of the smart sensor adapter is negligible.)

Note 3: This is a system level accuracy specification and is comprised of the ECH2O probe’s accuracy of ±0.03 m³/m³ typical (±0.02 m³/m³ soil specific) plus the smart sensor adapter accuracy of ±0.001 m³/m³ at +25°C (+77°F). There are additional temperature accuracy deviations of ±0.003 m³/m³ / °C maximum for the ECH2O probe across operating temperature environment, typical <0.001 m³/m³ / °C. (The temperature dependence of the smart sensor adapter is negligible.)

Inside this Package
- Soil Moisture Smart Sensor

Installation
This sensor measures the water content in the space immediately adjacent to the probe surface. Air gaps or excessive soil compaction around the probe can profoundly influence soil water content readings. Do not mount the probes adjacent to large metal objects, such as metal poles or stakes. Maintain at least 8 cm (3 inches) of separation between the probe and other objects. Any objects, other than soil, within 8 cm (3 inches) of the probe can influence the probe’s electromagnetic field and adversely affect output readings.

To install the ECH2O probe:
1. Use a thin implement like a trenching shovel, gardening spade, or flat bar to make a pilot hole in the soil. Make sure the hole is straight in the direction you will be orienting the probe. See Installation Considerations below.
2. Insert the probe into the hole, making sure the entire length of the probe is covered.
3. Insert a shovel into the soil a few inches away from the probe and gently force soil toward the probe to provide good contact between the probe and the soil.
4. Water the soil surrounding the sensor to facilitate settling of the soil.
5. Do not excessively pack or compress the soil adjacent to the sensor. The soil should contact the sensor surface, but should not be packed.

For deeper installation, excavate down to just above the level you wish to measure, then install the probe as described above.

If you need to calibrate your probe for the soil, you may want to gather soil samples from each sample depth at this time.

When removing the probe from the soil, do not pull it out of the soil by the cable! Doing so may break internal connections and make the probe unusable.

Installation Considerations
- The probe can be oriented in any direction. However, orienting the flat side perpendicular to the surface of the soil will minimize effects on downward water movement.
- Secure the sensor cable to the mounting pole or tripod with cable ties.
- The gray tube on the sensor cable that houses the smart sensor electronics is weatherproof; mount it to the pole or tripod outside the logger enclosure with cable ties.
- If you are running sensor cables along the ground, it is recommended that you use conduit to protect against animals, lawn mowers, exposure to chemicals, etc.
Connecting
To start using the Soil Moisture smart sensor, stop the logger and insert the sensor’s modular jack into an available port on the logger. If a port is not available use a 1-to-2 adapter (Part # S-ADAPT), which allows you to plug two sensors into one port. The next time you use the logger, it will automatically detect the new smart sensor. Note that the logger supports a maximum of 15 data channels; this sensor uses one data channel. Launch the logger and verify that the sensor is functioning correctly. See the logger user’s guide for more details about connecting smart sensors to the logger.

Operating Environment
The Soil Moisture smart sensor provides accurate readings for soil between 0 and +50°C (+32° and +122°F). The sensor will not be damaged by temperatures as low as -40°C (-40°F); it is safe to leave the sensor in the ground year-round for permanent installation. The smart sensor adapter electronics (housed in the gray tube on the sensor cable) are rated to +75°C (+167°F) and are mounted outside the logger enclosure and secured to the mounting pole. The cable and smart sensor adapter are weatherproof.

Operation
The Soil Moisture smart sensor measures the dielectric constant of soil in order to determine its volumetric water content. The dielectric constant of water is much higher than that of air or soil minerals, which makes it a sensitive measure of the water content. During operation, values of 0 to 0.4 m³/m³ (models EC-10 and EC-20), or 0 to 0.5 m³/m³ (model EC-5) are possible. A value of 0 to 0.1 m³/m³ indicates oven-dry to dry soil respectively. A value of 0.3 or higher normally indicates a wet to saturated soil. Values outside the operating range may be a sign that the sensor is not properly installed (poor soil contact or foreign objects are adjacent to the sensor) or that a soil-specific calibration is required. Note that sudden changes in value typically indicate that the soil has settled or shifted, which are signs that the sensor may not be installed properly or that it has been altered or adjusted during deployment. This sensor does not support measurement averaging. (See your logger user’s guide for more information about measurement averaging.)

Maintenance
The Soil Moisture smart sensor does not require any regular maintenance. If cleaning, rinse the sensor with mild soap and fresh water.

Calibration
The Soil Moisture smart sensor comes pre-calibrated for most soil types. If, however, your soil type has high sand or salt content, the standard calibration will not be accurate. In such cases, you will need to convert the data provided by the probe with a specific calibration for your individual soil type. To determine the soil specific calibration formula, refer to the Calibrating ECH2O Soil Moisture Probes application note, available at http://www.1800loggers.com.
**Soil Moisture Smart Sensor**

**Verifying Sensor Functionality**
To quickly check sensor functionality before deployment, perform the following two tests:

1. Wash the probe with water and let it dry.
2. Plug the sensor into the logger.
3. Open the logging software and go to the status screen.
4. Conduct an air test: Hold the sensor by the cable letting the sensor hang freely in the air, and compare the value in the status screen with the table below.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Air</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-SMA-M005</td>
<td>-0.119 to -0.106</td>
<td>+0.356 to +0.404</td>
</tr>
<tr>
<td>S-SMB-M005</td>
<td>-0.147 to -0.128</td>
<td>+0.401 to +0.466</td>
</tr>
<tr>
<td>S-SMC-M005</td>
<td>-0.193 to -0.139</td>
<td>+0.521 to +0.557</td>
</tr>
</tbody>
</table>

5. Distilled water test: Insert the probe in a room temperature container of fresh water, completely covering the entire ECH2O probe. Compare the value in the status screen with the table above.

If these tests pass, your sensor is working normally. If not, please contact Onset® for assistance. If you believe your sensor is defective or broken, you can send the smart sensor back to Onset for testing if needed. Contact Onset or your place of purchase for a Return Merchandise Authorization (RMA) number and associated costs before sending it.
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