Goodman Point Paleohydrology
Hovenweep National Monument
Wright Paleohydrological Institute
Wright Water Engineers, Inc.

GOODMAN POINT PALEOHYDROLOGY

Hovenweep National Monument

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www.wrightpaleo.com
Preface

By studying the ancient water supply of Goodman Point, our Wright Paleohydrological Institute (WPI) team developed an affinity for the prehistoric people who lived there and the evidence that they left for modern engineers and scientists to analyze and ponder.

These long-ago people knew how to harvest meager water supplies, and they built an active community under adverse circumstances. Juárez Spring served that community well, and the ancestral Pueblo people protected this spring by constructing a walled village around it. WPI’s primary objective was to define the rate of flow of the spring and its quality of water, coupled with estimating its recharge area and the geologic character of the bedrock source. WPI's work also included defining the hydrology of the supplemental water supply of Goodman Lake.

It is a rare opportunity to walk through the Goodman Point village and imagine the bustle of activity that took place there, with 500 to 800 human beings, some 700 years ago. Walking through the ruins of the village and noting numerous kivas and the building layout, one can appreciate the important role that Juárez Spring played in the everyday life of these people. They walled their village for protection against marauding bands of unwelcome visitors. Not far away, only a few miles to the west, their comrades in the Sand Canyon Pueblo led similar lives while harvesting limited water supplies.

Finally, Goodman Point and the Sand Canyon pueblos became silent as much of the Southwest was abandoned.

Sand Canyon
Dedication

This report on the waters of Goodman Point is dedicated to the archaeologists of the Southwest who have tirelessly studied its ancient people, the evidence they left behind, and the hardships that they endured.

In particular, we dedicate this report to David Breternitz and his wife, Barbara. Both have given their encouragement and support to WPI’s effort at Goodman Point and previously to our work at Mesa Verde since 1999.

More generally this report is dedicated to the people of Crow Canyon Archaeological Center who have made the ancestral Pueblo people come to life for young and old alike. In this regard, we note the intellectual contributions and support of Kristin Kuckelman and Bill Lipe who have enriched the field of archaeology.

Finally, WPI dedicates our report to the loyal and hard-working professionals of the National Park Service, and especially those of Hovenweep National Monument, who are safeguarding our national treasures for future generations.
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A corrugated pot sherd that was examined and replaced in the field.
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Introduction

In May 2010, the Wright Paleohydrological Institute (WPI) of Boulder, Colorado was granted authority to analyze the paleohydrology of the Goodman Point Group of Hovenweep National Monument by National Park Service Superintendent Corky Hays. The study was undertaken under ARPA permit No. 05-HOVE-01-ext1 held by the Crow Canyon Archaeological Center. WPI crews performed field studies at Goodman Point on May 15, July 21, July 31, September 11 and December 4, 2010. This report describes the results of WPI's field work, research and analysis of the paleohydrology of Goodman Point.

Hovenweep National Monument, located primarily along the Utah-Colorado border, contains the ruins of six ancestral Pueblo villages. Goodman Point Pueblo, WPI’s study site, is one of four of Hovenweep’s archaeological sites located in Colorado, along with Holly Canyon, Hackberry Canyon and Cutthroat Castle. The two village sites located in Utah are Cajon and Square Tower.

This report provides data and findings regarding the paleohydrology of Goodman Point unit of Hovenweep National Monument by WPI. The investigation was performed during the summer and fall of 2010.

Why Goodman Point?

Between 1996 and 2007, WPI evaluated five ancestral Pueblo water supplies at Mesa Verde National Park. Four of the supplies were reservoirs, and the most recent one studied was the Mug House cistern. The timeframe of the water supplies followed a natural progression. Morefield Reservoir, the first studied, was created during the Pueblo I period, about A.D. 750. Box Elder Reservoir was initiated about A.D. 800 and used into the Pueblo II period. The other two reservoirs—Far View and Sagebrush—were begun and used during the Pueblo II period into the Pueblo III period.

Use of the Mug House cistern was contemporaneous with that of the Goodman Point Pueblo. The cistern was abruptly abandoned at about the same time as the Goodman Point Pueblo.

After compiling data on the water use and practices of the ancestral Pueblo people during their water collection phases, information gaps remained regarding how the ancestral Pueblo people handled non-reservoir water supplies and what their water
handling practices were just before the region was depopulated at the end of the Pueblo III period. WPI's Mug House Cistern study of 2007 was initiated to partly address this gap in knowledge of thirteenth century practices.

The 2010 investigation of the Goodman Point unit allowed WPI to study two ancestral Pueblo water supplies:

1. Spring water supply sources that are still functioning in flow and quantity much as they did during the ancestral Pueblo occupation of the region, and

2. A reservoir filled by bare bedrock runoff.

**Objectives**

Objectives for the Goodman Point paleohydrology study were to characterize the paleohydrology of Goodman Point Pueblo, including Goodman Lake and Mona Spring. Paleohydrology is the study of ancient water handling and use.

**The Approach**

Over the course of five field trips, the WPI team analyzed the topography, geology and geomorphology within the setting of the cultural resources of the Goodman Point unit. GPS points were taken to facilitate mapping. The following specific tasks were performed:

1. **Juárez Spring No. 1 and No. 2** – A weir was used on three days, once in the morning and once in the afternoon, to measure diurnal flow in the downstream channel; the underlying strata at Spring No. 1 was inspected and described; water quality was tested for dissolved solids to ascertain field conductivity; and the location of no channel flow was determined. The research was supported by data from the Office of the State Engineer (SEO) published water rights and area well data, U.S. Geological Survey (USGS) data, and information from local well drillers.

2. **Mona Spring** (a.k.a. Teal Spring) – The drainage area of the spring was estimated and its point of origination in the arroyo was found.

3. **Goodman Lake** – The lake was surveyed to define volume and collect data for stage-capacity curves; the height and length of the existing modern dam was measured; the lake was augered to determine subsoils and check infiltration capacities; the area of slick rock drainage that is tributary to Goodman Lake was estimated; depressions in the surface of the slick rock were examined; flow connectivity was defined; and depression storage in inches of precipitation was field estimated.
4. Hydrogeology – The topographic drainage basins for Juárez Spring and Goodman Lake were inspected and outcrops and existing land use were identified; area homeowners were surveyed about static water levels in their wells; bedrock dip and strike at several locations were determined and checked against area-wide geologic maps to verify; the likely geologic tributary areas for both Juárez Spring and Mona Spring were defined; area-wide spring SEO data on water rights claims were reviewed; travel time and lag were estimated; area minerals were catalogued; and carbonate testing was performed to further refine the geologic analysis.

5. Water Utilization – the best path from Goodman Point Pueblo to Goodman Lake and its difficulty and length were determined; the likely best way to fill jars was considered with respect to a population of 500 to 800 people and a need to avoid contaminating the water supply; whether small ponds in the gully bottom were likely used was judged; and water collection efficiency was calculated.

6. Soil Analysis – soils in two drainage basins and adjacent lands were described in terms of physical and chemical characteristics; mapping was performed; and field infiltration tests were done.

7. Precipitation – U.S. Weather Service data for Cortez and Yellow Jacket were used to develop tables for average annual, average monthly and incremental precipitation with frequency. Rainfall/runoff discharge frequency and volume were estimated.

8. Palynology – Soil samples were taken from a likely agricultural area for pollen analyses. The question of how many acres of cropland were needed to sustain up to 800 people was evaluated.

9. Present Agriculture – The present-day crops were evaluated to determine the feasibility of dryland farming in the vicinity.

10. Astronomy – Field studies and research were conducted to evaluate the orientation of important ancestral Pueblo structures related to solar and lunar alignments.
In-office research was completed and was greatly facilitated by the large collection of data on the Unit compiled by the Crow Canyon Archaeological Center and the many authors in the reference list. Once the field and research data were assembled, WPI engineers and scientists used the data to assess the Goodman Point Pueblo site.

What Was Learned

The ancestral Pueblo people of the Mesa Verde region knew the importance of a reliable groundwater source and how to capitalize on its water yield. The team learned that these early people were industrious, and that they lived on the uplands of the Goodman Point area until they were compelled to congregate at a defensible location around Juárez Spring of Goodman Point. The pueblo and its enclosing wall protected the all-important water source. The people husbanded the flow of water from the spring and used jars to collect and transport water to their homes.

WPI determined that the Dakota Sandstone typically yielded about 2 gallons per minute (10 cubic meters per day) of good quality water at Juárez Spring. Mona Spring and Goodman Lake provided supplementary water supplies.

The ancestral Pueblo people were good hydrologists. It appears that they intended to stay for a long time, but they abandoned their homes about A.D. 1280, probably because of drought, civil unrest and lack of security.

Description of Goodman Point Unit

The Goodman Point unit is located in southwest Colorado in Section 4, Township 36 North, Range 17 West, approximately 11 miles northwest of Cortez, Colorado, at an elevation of 6,700 feet (Figure 1). The 143.3-acre unit contains the remains of a large Pueblo III village encircled by a defensive rock wall on the western rim of Goodman Canyon. The area was inhabited in Basketmaker III and Pueblo II times, but the Pueblo III period brought the greatest population, between 10,000 and 30,000 in the San Juan area (Kuckelman et al. 2009; Lipe and Varien 1999; Rohn 1989).

There are 42 specific sites contained within the Goodman Point unit of Hovenweep National Monument. The largest of these, Goodman Point Pueblo, includes “13 room blocks, 114 kivas, a great kiva, multiple bi-wall complexes, an estimated 450 rooms, multi-story structures, [and] numerous sections of village-enclosing wall” (Kuckelman et al. 2009).

The Goodman Point settlement was a concentration of about 500 to 800 people who had earlier lived in scattered family farmsteads. The village was occupied only a short time, from approximately A.D. 1260 until about 1280; this might have been the most populous village in the region between A.D. 1260 and 1275 (Kuckelman et al. 2009). Occupation of the Goodman Point settlement ended after a disastrous attack (Kuckelman et al. 2009), probably between A.D. 1275 and 1280, perhaps by other Pueblo people raiding for food.
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Goodman Point Pueblo (Site 5MT604) is the largest site in the Goodman Point unit and served as the community center between A.D. 1260 and 1280. The village featured a great kiva, plazas and a large, multistory, D-shaped building (Crow Canyon Archaeological Center 2010a). There were probably also outlying pockets of people. The Goodman Point area was one of the most densely populated in the northern San Juan region (Coffey and Copeland 2009).
Figure 1
USGS Topographic Mapping Showing the Goodman Point Unit and Surrounding Area
Figure 2
Tested Structures at Goodman Point Pueblo
(Kuckelman et al. 2009)

(From the Interim Descriptive Report of Research at Goodman Point Pueblo (Site 5MT604), Montezuma County, Colorado, 2005–2008 (Kuckelman et al. 2009), Figure 2 shows the tested structures at Goodman Point Pueblo and the ancient spring)
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The concentration of people at the Goodman Point Pueblo makes it a particularly good subject for the study of paleohydrology because it is possible to evaluate water needs and make comparisons with the estimated supply. Additionally, nutritional requirements of the population were compared to agricultural potential, although the focus of this study was water supply.

Juárez Spring was within the walled settlement and would have been the main source of water for the Goodman Point community. Other water sources that would have existed at the time were an ancient reservoir, now called Goodman Lake, and Mona Spring; both were about 0.5 mile south-southwest of the Goodman Point Pueblo.

The parcel of land set aside in 1889 (see Figure 4) was reduced during the 1950s. The National Park service now manages the 142-acre unit; other portions of the original reserve are currently managed by the Canyons of the Ancients National Monument or are privately owned. Goodman Point, Goodman Canyon and Goodman Lake were named for a cattle foreman, Henry Goodman, who worked in the area in the early 1880s (Horn 2004).

Juárez Spring water issues from the Dakota Sandstone at two distinct points. These are designated Juárez Spring No. 1 and Juárez Spring No. 2. The distance between the two springs is about 80 feet.

Climate

General

The climate of Goodman Point is semi-arid with 16 inches of average annual precipitation and temperatures ranging from as low as -26 degrees Fahrenheit (°F) in the winter and as high as 105°F during summer extremes. The frost-free period (temperature ≥ 32°F is approximately 140 days, and the typical growing season is from mid-May through the beginning of October. Table 1 provides precipitation and temperature averages, whereas Table 2 shows estimated incremental precipitation averages.
A review of successful dryland farming on Goodman Point and advice from Soil Scientist Douglas Ramsey of the Natural Resources Conservation Service (NRCS) suggest an annual precipitation for the Goodman Point area of about 16 inches per year. Figure 3 is a graph of annual precipitation.

A successful dryland bean crop in the Goodman Point area.
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To best analyze climate at Goodman Point, we chose to use what we learned at Mesa Verde National Park during our 1995 to 2006 research there.

Drs. Jeffrey Dean and William Robinson of the University of Arizona’s Laboratory of Tree-Ring Research in Tucson, Arizona developed reconstruction data for the Mesa Verde area for the period A.D. 481 through 1970. It resulted in an average annual precipitation estimate of 18.1 inches (Dean and Robinson 1977). WPI compared this with the modern Mesa Verde gage period of record from 1922 to 1970, with an average annual precipitation of 18.3 inches. The average annual precipitation from A.D. 1250 through 1280 is estimated at 17.9 inches. Because of this relative consistency, precipitation records from modern times were considered suitable for more detailed analyses of the ancient period.

The period in which Goodman Point Pueblo was occupied was a time of low rainfall in southwestern Colorado according to Dean and Robinson’s dendroclimatic analyses. The area experienced drought conditions from 1275 to 1300. In 1280, about the time Goodman Point was abandoned, rainfall at MVNP tended to be 25% below average. Drought conditions added stress to the already difficult living conditions of the ancestral Pueblo people.

Figure 3
Average Annual Precipitation
(Yellow Jacket 2 and 4 weather stations, Colorado)
(1962-2010)
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Geography

Southwest Colorado

Southwest Colorado geography ranges from 14,000-foot peaks to desert valley floors and supports such ecosystems as alpine forests and aspen groves, rolling mountains rich with ponderosa, piñon and juniper trees and lush green valleys. Sagebrush and yuccas decorate the ground as dramatic cliffs of purple and red and burnt orange rock lie on the horizon.

Montezuma County

Montezuma County is the most southwestern county in Colorado, with a population of almost 24,000. The county is home to many scenic and historical monuments, such as Mesa Verde National Park, Canyon of the Ancients National Monument, Yucca House National Monument and the Ute Mountain Ute Tribal Park. The county has a total area of 2,040 square miles, of which 2,037 square miles is land and 3 square miles (0.16%) is water.

Montezuma County is large, divided about equally in use between (1) tribal land, (2) federal land (administered by the National Park Service [NPS]), the United States Forest Service and the Bureau of Land Management), and (3) private, state and county land. The county ranges in elevation from about 6,000 feet (Colorado Plateau Desert) to more than 14,000 feet (Alpine Tundra). Much of the county is cropland that produces fruit and beans. Cattle and sheep ranching are also major land uses. The county has many reservoirs, lakes and ponds, including McPhee Reservoir, Colorado's second largest reservoir.

Cortez

The seat of Montezuma County is the City of Cortez. Cortez comprises about 5.5 square miles. It is a Home Rule Municipality and, with about 8,000 people, is the most populous town in Montezuma County. Cortez is at an elevation of 6,191 feet. The town serves as a border between mountain and desert, with an arid, high desert environment, but the La Plata and San Juan mountain ranges are clearly visible from town.
Mesa Verde

Nine miles east of the town of Cortez is the entrance to Mesa Verde National Park (MVNP). The park occupies about 80 square miles of rugged land covered in sandstone outcrops and piñon pine and Utah juniper forests. Elevations in the park range from about 6,100 to 8,400 feet. The terrain in much of the park is dominated by mesas and valleys oriented roughly north-south.

The area was occupied from about A.D. 600 (Basketmaker period) until about A.D. 1300 (Pueblo III period) by people who left behind kivas, mesa-top villages and cliff dwellings. MVNP was created in 1906 to protect its 4,700 archaeological sites, about 600 of which are cliff dwellings. MVNP is said to be home to some of the best preserved cliff dwellings in the world. Two Story House at Ute Mountain Ute Tribal Park, made famous by photographer Henry Jackson, is another area cliff dwelling that is well preserved.

Goodman Point Area

The Goodman Point area lies about 11 miles northwest of the town of Cortez and has a typical elevation of 6,700 feet. It is sparsely populated due to a lack of water, although a domestic water supply system was installed in the area in 2010, with numerous residential taps already hooked up by the end of 2010.

Goodman Point is an agricultural area that relies on dryland farming for growing mostly pinto beans, a low-value cash crop. Use of the land includes gas production and national monument property. Gas is being produced in the Goodman Point area and elsewhere on the McElmo Dome by the Kinder-Morgan Corporation. Goodman Point is a rich archaeological area that has been studied relatively little except for the recent investigations by the Crow Canyon Archaeological Center.

Springs of Goodman Point

About 20 springs have been identified in the Goodman Point area as shown on Figure 4, where homestead residences of the 1911 through 1925 period are also shown. The old Shiloh School had a low-yield water well and is now used as a residence. During this early period there were 71 homesteads on Goodman Point; most of these residents had to haul domestic water. Figure 4 is a map taken from the Goodman Point Historical Land-Use study by Marjorie Connolly (1992). It shows that the homesteads between 1911 and 1925 were typically 160 acres in size. The original Goodman Point archaeological site reserve covered one square mile and included Mona Spring and Goodman Lake.
Figure 4
Homestead Map, 1911-1925
(From Connolly [1992] Figure 4.2)
Geology

The sedimentary geologic units underling the Goodman Point area are generally flat lying, but with a slight dip to the northeast resulting from the McElmo Dome structural influence to the Southwest. The uppermost stratigraphic units listed from top to bottom are:

- Eolian soil
- Dakota Sandstone
- Burro Canyon Formation
- Morrison Formation,
- Junction Creek Sandstone

Of these five stratigraphic units, three are especially pertinent to the Goodman Point paleohydrology study: the Eolian soil, the Dakota Sandstone bedrock and the Burro Canyon Formation. The Dakota Sandstone, which is the source of water for Juárez Spring and Mona Spring (See Figure 5), and the Burro Canyon Formation tend to act as an integrated hydrogeologic unit.

Bedrock

Both the Dakota Sandstone and the Burro Canyon Formation support the water supply for the subject springs because both are at least partially saturated and control the regional groundwater regime as water flows slowly downslope to create occasional springs and seeps. It is thought that, regionally, there may be a decade-long lag between precipitation and flow from springs and seeps.

Dakota Sandstone

Based on review of geologic mapping and observations during site visits, the bedrock geologic unit most directly associated with Juárez Spring is the Dakota Sandstone (Figure 6).

As described by the USGS on Map I-629 (Haynes et al. 1972), the Dakota Sandstone is dominantly a yellowish-brown to gray quartzite and conglomeratic sandstone in thick beds with subordinate thin lenticular beds of gray claystone, impure coal, carbonaceous papery shale, and gray friable carbonaceous sandstone, and locally occurring with a coarse basal conglomerate. Its thickness in the Goodman Point area is several hundred feet.

Observed outcrops of Dakota Sandstone bedrock exposed in the vicinity of Goodman Point and Juárez Spring are yellowish-brown sandstone. These outcrops form cliff faces of approximately 4 to 10 feet in the Juárez Spring drainage. Other bedrock exposures represent the tops of these sandstone units where
Figure 5
Goodman Point Area Geology
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surface water and wind have removed the overlying soils and revealed an irregular surface (including ancient ripple marks and fractures).

The Dakota Sandstone has a low permeability and is well known for its dry wells on Goodman Point lands.

Attempts were made to assess the geologic materials underlying the sandstone outcrop in the vicinity of Juárez Spring. However, detailed examination of those materials was forestalled by plant roots, tufa and soils, which concealed the outcrop, and by limitations on ground-disturbing activities within the national monument. (NOTE: tufa deposits are a precipitated calcium carbonate [predominantly calcite and aragonite] from spring-fed heated and/or ambient-temperature waters). Observations of exposed Dakota Sandstone bedrock in other parts of this drainage revealed occasional gray shale and claystone between sandstone exposures. It is likely that these materials underlie the sandstone outcrops that typify the area immediately above Juárez Spring and therefore force the groundwater to the surface because of their relative impermeability.

During the September 2010 visit, some areas of standing water were noted near exposed sandstone outcrops, suggesting a relatively slow infiltration rate through these bedrock units. However, there was no evidence that these sandstone units were completely impermeable and likely they have reasonably good infiltration rates where they are fractured or poorly cemented.

Figure 6
Goodman Point Area Geology and Drainage Basins
In numerous locations, a white material had been deposited along the noted small fractures within the Dakota Sandstone. Identification of this material as a carbonate was confirmed when a dilute hydrochloric acid (10% HCL) effervesced profusely when applied to a fresh surface of this white material. A similar analysis on a fresh sandstone surface resulted in little or no effervescence.

Because of the irregular nature of the exposed Dakota Sandstone outcrops in the area, strike and dip measurements were varied and should be considered general rather than precise. For example, available geologic mapping for the area suggests that the regional dip is about 3° to the east/northeast as a result of the location of the McElmo Dome to the west/northwest.

Strike and dip observations in the vicinity of Mona Spring and Goodman Lake tend to confirm this structural orientation. However, strike and dip observations in the immediate vicinity of Juárez Spring suggest a dip angle of approximately 5° to the southeast. The small expanse of exposed bedrock prevented further assessment of this anomaly. However, structural variability in the bedrock exists and may be a partial explanation for the location of Juárez Spring and the reliability of this water source for the ancient culture that inhabited the area (Figure 7).
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Burro Canyon Formation

Underlying the Dakota Sandstone is the geologically similar, but older, Burro Canyon Formation. Often, the two are combined by hydrogeologists when analyzing regional hydrology. The Burro Canyon strata extend beneath the ground surface about 1,000 feet or more.

A Burro Canyon Formation well was detailed to a depth of 1,095 feet in 1997 at a location about one mile southeast of Goodman Lake. The hole was dry, which attests to the difficulty of groundwater development in the Burro Canyon Formation that results from a lack of open cracks and joints.
Soils

The soil groups for the Goodman Point area as provided by the United States Soil Conservation Service (SCS) are shown on Figure 8. The dominant soil in the surface drainage upstream of Juárez Spring and Mona Spring is the Wetherill loam, described as follows:

**Soil Depth**: More than 80 inches.

**Capacity to transmit water**: Moderately high (0.2 to 0.6 inches/hour).

**Salinity**: The soil is non-saline.

**Available water capacity**: The soil can store about 11 inches of water.

**Drainage class**: Well drained.

**Hydrologic soil group**: Group B with a moderate infiltration rate, i.e., there is a tendency for rainfall to seep into the ground rather than to run off.

**Calcium Carbonate**: The presence of calcium carbonate in the soil increases with depth with little in the top seven inches but ranging up to 30 percent in the lower soils below four feet of depth.

**Silt and clay**: About 60 to 80 percent of the soil is silt and clay and about thirty percent is sand.

**Erosion**: The erosion potential is moderate at 0.37 on a scale of 0.02 to 0.69. The top three inches can lose up to 5 tons of soil per acre per year due to erosion.

This deep soil with a high water-holding capacity and good infiltration is excellent for dryland farming.

Excess water will drain freely to the underlying bedrock layer that is typically more than 80 inches below the surface, but the water will not drain to the bedrock until the available water capacity is satisfied. A theoretical mass balance of water storage analysis could be performed balancing monthly precipitation against vegetation root uptake. This would show only a small movement downward into the bedrock.

The Wetherill loam soil has a high calcium carbonate content at depth, generally below four feet. Deep percolation for the soil will carry calcium carbonate into the Dakota Sandstone. This calcium carbonate is found in the water that issues from Juárez Spring. The water quality tests verify that Juárez Spring water is derived from water percolating through the soil cover as do the chemical tests on the deposits in the cracks of the surface Dakota Sandstone.
Figure 8
Soil Map of Goodman Point Area Based on SCS Soil Survey
On July 31 and September 11, 2010, four field infiltration tests were conducted at two locations. A Decagon handheld Mini-Disk Infiltrometer was used, which measures soil hydraulic conductivity in any soil type. The infiltrometer is constructed of a polycarbonate tube with a semi-permeable stainless steel sintered disk on the bottom and an adjustable steel tube above.

Infiltration of the water through the soil surface is affected by many factors such as foot traffic, natural vegetation and farming. For instance, foot traffic can compact the soil surface and cause it to change from permeable to impermeable. For this reason, it is preferable to use the Natural Resources Conservation Service (NRCS) group designation that ranges from A to D, with Group A having the highest infiltration rate and lowest storm runoff. The field tests were performed at Goodman Point for verification purposes. The Wetherill soils are Group B, which explains their low rainfall-runoff, water absorption and ability to support dryland agriculture.

The first field test, on July 31, 2010, was performed in Wetherill soil with natural vegetation. The result of 0.5 inches per hour is consistent with the NRCS’s estimate of Wetherill soil capacity to transmit water.

The subsequent three field infiltration tests on September 11, 2010, were performed on the modern embankment of Goodman Lake to generally characterize the potential seepage through the embankment and to gather field data for the lake. The test results were mixed on the upstream face of the man-made structure, ranging from 0.3 to 1.5 inches per hour. However, the interior of the embankment would be expected to be much less permeable.
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Geohydrology

Goodman Point Geohydrology

A regional groundwater analysis of the Dakota Sandstone/Burro Canyon Formation aquifer by S.M. Smith, K.E. Kolm and J.E. McCray (2007) estimated hydraulic conductivity of 0.2 meters per day (0.65 foot per day) for the roughly 1,000-foot-thick bedrock layer. This represents a very low permeability of 0.00007 cubic feet per day per square foot, or 0.005 gallons per day per square foot. The permeability is secondary in nature, i.e., from joints and fractures in the bedrock.

Additional hydrogeologic information was obtained from field studies and a review of the Colorado State Engineer’s Office water well permit database. These data provide information on the location of permitted water wells in the vicinity of Juárez Spring. Available data indicate that there is saturation of the Dakota Sandstone and Burro Canyon Formation bedrock (with water level depths in the range of 20-50 feet) with limited yield potential (i.e., 0.5-2 gpm). These data were confirmed by discussions with several property owners on September 11, 2010 who either have wells or have attempted to construct wells on their property.

Geologic strike and dip field measurements in the vicinity of Juárez Spring are approximately 90° from those identified on the available geologic mapping for the area. Although the geologic mapping is considered to provide the best regional information about the geologic structure, there is a likelihood of local anomalies. Overall, the geologic structure suggests that the geologic tributary area to Juárez Spring is to the west/northwest of the site. Goodman Point is a relatively flat expanse of land which is the high point (and hydrologic divide) between Goodman Canyon (to the east) and Sand Canyon (to the west). The presence of Sand Canyon serves to limit the potential bedrock tributary area.

Using geologic mapping, field observations, and reasonable assumptions about the subsurface, it appears that the likely geologic tributary area is roughly 500 acres. This is relatively consistent with the area identified in the hypothesis with which WPI commenced field work.

Hypothesis

To focus the research prior to our second field evaluation, the following hypothesis was prepared by WPI relative to the hydrologic character of Juárez Spring:

**Hydrologic Hypothesis**

*The partially saturated Dakota Sandstone/Burro Canyon Formation north and west of the Goodman Point Juárez Spring drains by gravity at the rate of about 3 acre-feet (3,700 cubic meters) per year to the spring.*
Occasionally, localized precipitation may double the 2-gallon-per-minute (7.6-liter-per-minute) spring flow.

With 0.5 percent of the annual precipitation reaching the groundwater reservoir, the likely geologic tributary area is 500 to 600 acres (2.4 square kilometers).

The relatively high field capacity of the surficial soils allows considerable interaction with infiltrated rainfall and thus a chemical change as the water moves through. Some of this water migrates slowly into the Dakota Sandstone where deposition of carbonate minerals can occur, or it continues downward through fractures and poorly cemented intervals to less permeable underlying units and then along bedding planes until it daylights at springs or seeps. Known area springs such as Juárez and Mona have tufa or travertine deposits associated with their main discharge location, which further confirms the dissolution and transport of carbonate in the groundwater flow path.

These findings for Juárez Spring generally apply to Mona Spring, which was adjudicated for 0.5 gallons per minute as Teal Spring.

The low hydraulic conductivity of the Dakota Sandstone results in a long lag time between precipitation and outflow. However, the investigations to date do not provide an adequate basis for estimating lag time.

On September 10-11, 2010, additional field observations were conducted to assess the validity of the hydrologic hypothesis. Observations documented in the Geology, Hydrogeology and Hydrology sections of this report serve to confirm the hypothesis posed above. The hypothesis suggests that the recharge source for Juárez Spring in ancient times (as well as presently) was natural precipitation falling on the approximate 500 acres of hydrologic and geologic drainage area upstream of the spring. A summary by Justice Greg Hobbs titled “A Perfect Point” about the September 10-11, 2010, field studies is provided as Attachment A.

Wells

A survey of area well permits shows that wells in the vicinity range from 65 to 1,100 feet deep and yield between 0.75 and 15 gallons per minute with some wells being dry holes. The work of a hydrologist is to corroborate the occurrence of water and its characteristics by ground truthing. We know that Juárez Spring had a reliable flow in ancient times, and that it now yields about 2 gallons per minute from an outcrop in the Dakota Sandstone. Its topographic drainage basin includes 167 acres lying to the northwest.

Nonetheless, it is evident that Juárez Spring is dependent on the Dakota Sandstone aquifer and favorable piezometric sloping surfaces within the bedrock. To confirm the piezometric elevations and slopes, the available published data for Goodman Point water wells was analyzed for location and depth to static water levels.
Eight constructed water wells were found to have been drilled in the area of interest as tabulated in Table 3. Each of the wells was identified with their depth, yield and static water level. Three of the water wells were found by their location to be pertinent to the analysis of Juárez Spring. Logs of the three wells are shown in Figure 9.

By analyzing the location of each of the three wells and noting their static water levels, we concluded that the water levels ranged from 6,650 to 6,700 feet in elevation and were within the geologic contributing drainage basin of Juárez Spring. The static water levels confirmed a piezometric water level slope to the lower-lying Juárez Spring at elevation 6,640 feet. Because the existing wells have small yields and are not regularly relied upon, their impact on Juárez Spring yield is not significant.

Additional information on approximate static groundwater levels and the occurrence of wells was obtained through observations and personal interviews with local residents, as follows:

Residence # 1: Darren Fulks of 17585 County Road P stated that he never tried to drill a well and has always relied on hauled water.

Residence # 2: This residence has a water well, but the owner was not available.

Residence # 3: Our interview determined that a low-yielding well had a static water level at 30 feet of depth.

Residence # 4: The homeowner reported that he had drilled three wells and all were dry holes.

Residence # 5: Located in the water contributing area of Mona Spring, the resident reported a static water level of 30 to 65 feet in the Dakota Sandstone. Due to the low permeability of the aquifer, the well has a very low yield. The resident stated that water hauling is common at Goodman Point.
The personal interviews provided static water data that were consistent with the SEO published well log data and confirmed that groundwater levels in the area of the Juárez Spring and Mona Spring structural geology drainage basin would support the theory that water within the Dakota Sandstone flows by gravity to each of the two springs.

Table 3
Proximal Well Permit Summary
Goodman Point Group, Hovenweep National Monument
Montezuma County, Colorado

<table>
<thead>
<tr>
<th>Permit No.</th>
<th>Permit Status</th>
<th>Subdivision Name</th>
<th>Lot</th>
<th>Location</th>
<th>Coordinates</th>
<th>UTM Coordinates</th>
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<td></td>
<td></td>
<td></td>
<td>Twn Rng</td>
<td>Dist</td>
<td>E/W Dist</td>
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<tr>
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<td></td>
<td></td>
<td>37 N 17 W 32 SW SE</td>
<td>510 S 3480 E</td>
<td>168170.7 4147431.7</td>
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<td>233420</td>
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<td></td>
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<td></td>
<td></td>
<td>37 N 17 W 34 SE SW</td>
<td>750 S 3620 W</td>
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<tr>
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<td>1</td>
<td>36 N 17 W 4 NW NW N</td>
<td>42 N 1250 W</td>
<td>169698.5 4147208.7</td>
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<td>350 N 450 E</td>
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<td>83794</td>
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<td>36 N 17 W 8 NE SE N</td>
<td>1700 N 1300 E</td>
<td>168842.7 4145309.9</td>
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<tr>
<td>201886</td>
<td>Well Constructed</td>
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<td></td>
<td>36 N 17 W 10 SW NW N</td>
<td>2260 S 30 W</td>
<td>170850.1 4144822.2</td>
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Permit No. | Permit Status | Permitted Uses No. 1 | Aquifer Name | Permit Date Issued | Expires | Date Constructed | Comment |
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<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
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<td>DOMESTIC ISSUED UNDER PRESUMPTION 3b-IIA ALL UNNAMED AQUIFERS</td>
<td></td>
<td>10/26/1983</td>
<td></td>
<td>31306</td>
<td></td>
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<td>145013</td>
<td>WELL RESOLUTION 51-85</td>
<td>HOUSEHOLD USE ONLY DAKOTA</td>
<td></td>
<td>8/15/1986</td>
<td>8/26/1986</td>
<td>YIELD REPORTED AS 15 GPH</td>
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<td>Well Constructed</td>
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<td>7/17/2001</td>
<td>7/17/2003</td>
<td>7/18/2001 Square 40 acre 1/4, 1/4</td>
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Table 3, continued

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<th>Perforations Top</th>
<th>Perforations Bottom</th>
<th>Yield</th>
<th>SWL</th>
<th>Applicant Name</th>
<th>Mailing Address</th>
<th>City</th>
<th>State</th>
<th>Zip</th>
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<td>200</td>
<td>0.75</td>
<td>130</td>
<td>EVANS RODNEY L &amp; KATHRYN</td>
<td>PO BOX 844</td>
<td>NORWOOD</td>
<td>CO</td>
<td>81423</td>
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<td>233420</td>
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<td>261</td>
<td>50</td>
<td>70</td>
<td>2</td>
<td>30</td>
<td>WILSON JAMES E AND VIDA V</td>
<td>19048 COUNTY ROAD S</td>
<td>CORTEZ</td>
<td>CO</td>
<td>81321</td>
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<td>65</td>
<td>98</td>
<td>4</td>
<td>52</td>
<td>BELT D</td>
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<td>CORTEZ</td>
<td>CO</td>
<td>81321</td>
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<td>30</td>
<td>103</td>
<td>0.25</td>
<td>38</td>
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<td>175</td>
<td>15</td>
<td>130</td>
<td>CHAPPELL STEVE D</td>
<td>15989 COUNTY ROAD P</td>
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<td>OLIVER TROY M.</td>
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<td>CO</td>
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<td>Well Constructed</td>
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<td></td>
<td></td>
<td>STAATS LARRY D.</td>
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<td>4.5</td>
<td>870</td>
<td>MAHAFFEY CHARLES L</td>
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<td>CORTEZ</td>
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**Rock Outcrop**

The Goodman Point area soils are underlain at a shallow depth by the Dakota Sandstone. WPI concluded that the bedrock aquifer yielding water to the two springs was recharged by local rainfall. For this reason, a survey was conducted of area-wide rock outcrops.

The survey of the Goodman Point geologic drainage basin identified only a few outcrop areas, two of which were in the ephemeral channels leading to Juárez Spring and to Mona Spring. The third outcrop was high in the Mona Spring basin at an elevation of 6,830 feet.

This survey showed that the thick red soils are resistant to erosion and that the Dakota Sandstone was recharged via limited percolation through the soil cover. This route of water to the bedrock aquifer finding is supported by the high calcium carbonate concentration in the water of Juárez Spring. That is, the calcium is leached from the overlying soil cover.

A rock outcrop near Mona Spring.
Juárez Spring

Juárez Spring is in the center of Goodman Point Pueblo at an elevation of 6,640 feet (Schelz and Moran 2005) (Figure 10). The spring was the reason the village was built in this location. The spring issues from a six-foot Dakota Sandstone rock outcrop and has two discharge points about 80 feet apart. Juárez Spring flows to the southeast through the village’s south-central segment (Kuckelman et al. 2009).

The NPS has been monitoring Juárez Spring flow several times per year since 2004. These measurements are provided in Table 4. The NPS measuring location is in a gully bottom downstream from the two springs. As a result, occasionally the measurements might be influenced by surface runoff.

Table 4
Juárez Spring Flow as Monitored by NPS Staff

<table>
<thead>
<tr>
<th>Date</th>
<th>Flow (gpm)</th>
<th>Date</th>
<th>Flow (gpm)</th>
<th>Date</th>
<th>Flow (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/9/2004</td>
<td>1.92</td>
<td>2/10/2006</td>
<td>1.61</td>
<td>6/7/2007</td>
<td>1.84</td>
</tr>
<tr>
<td>12/3/2004</td>
<td>1.90</td>
<td>5/2/2006</td>
<td>2.18</td>
<td>10/15/2009</td>
<td>1.49</td>
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<td>1/25/2005</td>
<td>2.68</td>
<td>6/12/2006</td>
<td>1.60</td>
<td>2/18/2010</td>
<td>2.15</td>
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<tr>
<td>6/30/2005</td>
<td>2.29</td>
<td>11/20/2006</td>
<td>1.92</td>
<td>7/12/2010</td>
<td>1.73</td>
</tr>
<tr>
<td>7/21/2005</td>
<td>1.83</td>
<td>12/12/2006</td>
<td>1.86</td>
<td>8/16/2010</td>
<td>1.67</td>
</tr>
<tr>
<td>10/24/2005</td>
<td>2.17</td>
<td>2/19/2007</td>
<td>2.43</td>
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</table>

*Surface runoff likely included.
Figure 10
Juárez Spring and Area Topography
On July 31, September 11 and December 4, 2010, WPI made flow measurements at Juárez Spring at the same location used by the NPS and using NPS's measuring device. Measurements were obtained by using a steel plate with metal pipe welded to an opening at the approximate center of the plate. This plate was forced into the ground to back up and force flow through the pipe, thus allowing physical measurement of volume over time.

The WPI measurements were made at least twice each day—one in the morning and once in the afternoon. Each test involved flow measurements that were repeated to verify their accuracy. The NPS measuring site is in a gully bottom amongst thick vegetation, including willows. WPI observed that afternoon flow measurements at Juárez Spring were lower than morning measurements. On September 11, for example, the air temperature was cool at 9:30 am and warm at 4:00 pm, with a difference in discharge of 16 percent. WPI attributed this difference to differential vegetal evapotranspiration and concluded that the actual combined yield of the spring at the two points of issuance from the bedrock may be higher than the measured rate of flow by as much as a gallon per minute during the growing season.

Recent USGS studies by John Moody, Brian Ebel and Francis Rengers indicate that willow plants like those present at Juárez Spring will cause diurnal fluctuations in groundwater levels. The thirsty willows cause accelerated evapotranspiration during warmer periods (Rengers 2010).

The impact of the vegetation consumptive use depletion on the water yield of the spring prior to the gully bottom measurements was confirmed on July 31, September 11 and December 4, 2010. Morning and afternoon measurements were as shown in Table 5.
### Goodman Point Paleohydrology

#### Table 5
Diurnal Flow Measurements at Juárez Spring

<table>
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<th></th>
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<tr>
<td></td>
<td>10:00am</td>
<td>12:30pm</td>
<td>3:20pm</td>
</tr>
<tr>
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<td>6</td>
<td>1.89</td>
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<td>1.75</td>
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<tr>
<td>Average</td>
<td>1.94</td>
<td>1.70</td>
<td>1.77</td>
</tr>
</tbody>
</table>

Values are in Gallons per Minute (gpm)

Cattails at Juárez Spring
Goodman Point Paleohydrology

Mona Spring

Mona Spring is derived from an outcrop of the Dakota Sandstone in the bed of a small, unnamed tributary shown below. Mona Spring is also known as Teal Spring on the legal documents of the NPS. Its likely water yield is about 0.5 gallons per minute, and, as such, much of the flow is quickly absorbed by native vegetation during the summer. Nevertheless, the spring does create a pool at the base of the rock outcrop in the ephemeral gully channel.

The topographic drainage basin of the Mona Spring gully has 543 acres that range from 6,700 to 7,020 feet in elevation. The flow of Mona Spring, however, is a result of the bedrock aquifer levels and not runoff from the topographic watershed.

The team found the location of Mona Spring during the July 21, 2010, field visit. A description of this discovery, “The search for Mona Spring” by Justice Greg Hobbs, is attached as Appendix B.

Water Rights

The United States holds water rights for Juárez Spring (referred to as “Goodman Point Spring” in the decree) and Mona Spring (referred to as “Teal Spring” in the decree). The Juárez Spring water rights application was initiated by the NPS and the Mona Spring application was filed by the Bureau of Land Management.

Juárez Spring. The application was filed with Water Division No. 7 Water Court in December, 1976. On July 31, 1997, Judge Timothy Patalan issued a decree (Case No. W-1633-76A) for numerous Hovenweep springs that included Juárez Spring as a reserved water right.

Juárez Spring: 0.01 cfs (4.5 gpm)

Mona Spring. This application for the Bureau of Land Management was filed with the same water court on August 10, 1995 for numerous springs that included Teal Spring (a.k.a. Mona Spring). The decree for the water right was dated November 7, 1996 and signed by the water referee. The appropriation date is June 28, 1982.
Goodman Point Paleohydrology

Teal Spring (a.k.a. Mona Spring): 0.0011 cfs (0.5 gpm)

The water right decrees for the two subject springs were based on credible testimony and/or documentation. The rates of flow awarded are consistent with WPI’s estimates of rate of maximum flow.

Surface Hydrology

The permeable soils of the Goodman Point area absorb much of the rainfall; this is the reason that dryland farming is feasible there. However, there is frequent runoff from small exposed bedrock areas such as that which provides a water source for Goodman Lake.

The potential of storm runoff and flooding in the basins, particularly Basin A, would have been well known by the ancient Goodman Point residents. As a result, they would have limited valley bottom development in and near the channels. Water collection pools in the channel bottoms would have occasionally washed out or become filled with sediment, but could have been rebuilt easily.

Where the channel of Basin A enters Goodman Point Pueblo, there was a defensive wall across the channel. This segment of wall, now missing, would have provided an opening for reasonable sized flood flows, but would have restricted human access.

Goodman Lake

One-half mile south-southwest of Goodman Point Pueblo is Goodman Lake, below. Goodman Lake represents an ancestral Pueblo water harvesting masterpiece. The lake is situated at the lower end of a 3.1-acre Dakota Sandstone that serves as a rainfall-runoff generator.

The Pueblo III period was marked by an increase in the development and use of domestic water supplies (Lipe and Varien 1999). Goodman Lake began as a natural depression that was dug out and likely dammed with earth, rocks and mud. The ancient lake was modified by nineteenth and twentieth century homesteaders who dredged the pool and augmented the now 7-foot-high embankment to potentially impound more water than formerly. Modern ranchers used water from Goodman Lake to water their livestock and fill barrels.

The main portion of the existing dam is 207 feet long; the lake averages about 30 feet wide and has a 20,000-gallon capacity (Wilhusen 1997). The
reservoir was altered by people who came after the ancestral Pueblo people, although the bedrock runoff surface is unchanged and can therefore provide data on the frequency and amount of runoff and water storage during ancient times.

**Bedrock Watershed**

The 3.1-acre Dakota Sandstone runoff area slopes at approximately 3% to Goodman Lake. Detailed hydraulic analyses were performed on the bedrock surface to determine the detention storage resulting from the pitted surface of the bedrock. The hydraulic testing resulted in a determination that the detention storage is equivalent to one-tenth inch of rainfall over the entire surface.

We estimate that, due to other losses such as evapotranspiration off of the warm bedrock, a loss of 0.25 inches would be reasonable.

By analyzing the rainfall depth-frequency from modern precipitation records, we estimated how often and how many times per year water would flow into the reservoir, and in what volumes. Estimates of evaporation from the lake surface (Table 6) and seepage were also considered in our judgment of the suitability of Goodman Lake as a water supply source.

A portion of the bedrock runoff area that feeds Goodman Lake.
Goodman Point Paleohydrology

Table 6
Evaporation Potential for Goodman Lake
(Based on gross evaporation of 51.5 inches from NOAA Technical Report NWS 33 and data from Yellow Jacket Precipitation Station)

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly Evaporation Distribution (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Gross Evaporation (inches)&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Average Year Precipitation (inches)&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Effective Precipitation (inches)&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Net Unit Evaporation (inches)&lt;sup&gt;5&lt;/sup&gt;</th>
<th>Net Unit Evaporation (feet)&lt;sup&gt;6&lt;/sup&gt;</th>
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<td>0.98</td>
<td>7.26</td>
<td>0.60</td>
</tr>
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<td>August</td>
<td>13.0</td>
<td>6.70</td>
<td>1.68</td>
<td>1.18</td>
<td>5.52</td>
<td>0.46</td>
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<td>September</td>
<td>11.0</td>
<td>5.67</td>
<td>1.72</td>
<td>1.20</td>
<td>4.46</td>
<td>0.37</td>
</tr>
<tr>
<td>October</td>
<td>7.5</td>
<td>3.86</td>
<td>1.86</td>
<td>1.31</td>
<td>2.56</td>
<td>0.21</td>
</tr>
<tr>
<td>November</td>
<td>4.0</td>
<td>2.06</td>
<td>1.34</td>
<td>0.94</td>
<td>1.12</td>
<td>0.09</td>
</tr>
<tr>
<td>December</td>
<td>1.5</td>
<td>0.77</td>
<td>1.32</td>
<td>0.92</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Annual</td>
<td>100</td>
<td>51.5</td>
<td>15.8</td>
<td>11.06</td>
<td>40.94</td>
<td>3.41</td>
</tr>
</tbody>
</table>

<sup>1</sup>From SEO Guidelines (2/28/95) for sites above 6,500 feet.
<sup>2</sup>Annual value from NOAA Technical Report NWS 33.
<sup>3</sup>Average annual precipitation data from NOAA recording station at Yellow Jacket.
<sup>4</sup>Equals average year precipitation x 0.70.
<sup>5</sup>Gross evaporation minus effective precipitation.
<sup>6</sup>Net unit evaporation divided by 12.
Goodman Point Paleohydrology

Goodman Lake Capacity

Field surveys of Goodman Lake defined contours, established its size and shape and determined the stage-capacity relationship. The contour map of the lake is shown in Figure 11 and the stage-capacity curve is shown in Figure 12.

The volume of storage at Goodman Lake up to the high water line at 2.25 feet of depth is 0.07 acre-foot (22,000 gallons). Using precipitation data in Table 7, our hydrologic analysis of water yield to Goodman Lake indicated that water would flow into the lake, on the average, at the volumes and frequencies listed in Table 8.

Seepage and evaporation of water from the lake was evaluated with the conclusion that the lake would have often been dry. However, the frequency of even small inflows was sufficient to conclude that Goodman Lake was a good supplemental domestic water supply for the people of Goodman Point Pueblo.

Table 8
Goodman Lake Volume/Frequency Water Yield

<table>
<thead>
<tr>
<th>Measurable Runoff (gallons)</th>
<th>Times Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000</td>
<td>23</td>
</tr>
<tr>
<td>10,000</td>
<td>18</td>
</tr>
<tr>
<td>25,000</td>
<td>7</td>
</tr>
<tr>
<td>50,000</td>
<td>2</td>
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</table>

Table 7
Goodman Lake Water Yield
Storms Greater Than 0.25 inches, Yellow Jacket Gage

<table>
<thead>
<tr>
<th>Year</th>
<th>ft3</th>
<th>AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>27840</td>
<td>0.64</td>
</tr>
<tr>
<td>1963</td>
<td>50400</td>
<td>1.16</td>
</tr>
<tr>
<td>1964</td>
<td>21600</td>
<td>0.50</td>
</tr>
<tr>
<td>1965</td>
<td>51280</td>
<td>1.18</td>
</tr>
<tr>
<td>1966</td>
<td>20640</td>
<td>0.47</td>
</tr>
<tr>
<td>1967</td>
<td>24960</td>
<td>0.57</td>
</tr>
<tr>
<td>1968</td>
<td>23520</td>
<td>0.54</td>
</tr>
<tr>
<td>1969</td>
<td>15200</td>
<td>0.35</td>
</tr>
<tr>
<td>1970</td>
<td>37360</td>
<td>0.86</td>
</tr>
<tr>
<td>1971</td>
<td>41040</td>
<td>0.94</td>
</tr>
<tr>
<td>1972</td>
<td>47760</td>
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</tr>
<tr>
<td>1973</td>
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<td>1974</td>
<td>24800</td>
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<tr>
<td>1975</td>
<td>5520</td>
<td>0.13</td>
</tr>
<tr>
<td>1976</td>
<td>27360</td>
<td>0.63</td>
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<tr>
<td>1977</td>
<td>28960</td>
<td>0.66</td>
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<tr>
<td>1978</td>
<td>24800</td>
<td>0.57</td>
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<tr>
<td>1979</td>
<td>15040</td>
<td>0.35</td>
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<tr>
<td>1980</td>
<td>27440</td>
<td>0.63</td>
</tr>
<tr>
<td>1981</td>
<td>22480</td>
<td>0.52</td>
</tr>
<tr>
<td>1982</td>
<td>30730</td>
<td>0.71</td>
</tr>
<tr>
<td>1983</td>
<td>18320</td>
<td>0.43</td>
</tr>
<tr>
<td>1984</td>
<td>17440</td>
<td>0.40</td>
</tr>
<tr>
<td>1985</td>
<td>36240</td>
<td>0.83</td>
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<tr>
<td>1986</td>
<td>58560</td>
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<td>1987</td>
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<tr>
<td>1988</td>
<td>22560</td>
<td>0.52</td>
</tr>
<tr>
<td>1989</td>
<td>20160</td>
<td>0.46</td>
</tr>
<tr>
<td>1990</td>
<td>34560</td>
<td>0.79</td>
</tr>
<tr>
<td>1991</td>
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<td>1992</td>
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<td>1993</td>
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<td>1994</td>
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<tr>
<td>1995</td>
<td>21040</td>
<td>0.48</td>
</tr>
<tr>
<td>1996</td>
<td>40960</td>
<td>0.94</td>
</tr>
<tr>
<td>1997</td>
<td>39760</td>
<td>0.91</td>
</tr>
<tr>
<td>1998</td>
<td>18080</td>
<td>0.42</td>
</tr>
<tr>
<td>1999</td>
<td>21360</td>
<td>0.49</td>
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<tr>
<td>2000</td>
<td>24400</td>
<td>0.56</td>
</tr>
<tr>
<td>2001</td>
<td>18560</td>
<td>0.43</td>
</tr>
<tr>
<td>2002</td>
<td>23440</td>
<td>0.54</td>
</tr>
<tr>
<td>2003</td>
<td>35680</td>
<td>0.82</td>
</tr>
<tr>
<td>2004</td>
<td>42800</td>
<td>0.98</td>
</tr>
<tr>
<td>2005</td>
<td>33920</td>
<td>0.78</td>
</tr>
<tr>
<td>2006</td>
<td>28080</td>
<td>0.64</td>
</tr>
<tr>
<td>2007</td>
<td>26400</td>
<td>0.61</td>
</tr>
<tr>
<td>2008</td>
<td>13040</td>
<td>0.30</td>
</tr>
<tr>
<td>2009</td>
<td>13040</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Average: 28449.8 0.65

Notes:
Columns for each gaging station represent total precipitation for the year less 0.25 inches for each storm event.
Goodman Point Paleohydrology

Figure 11
Goodman Lake 1-foot Contours

Figure 12
Stage Capacity Curve

Notes:
1.) All contours shown are approximate.
The modern high-water line of the lake is clearly defined by vegetation (above) and rock staining (below).
Directions, a poem about Goodman Lake by team member Greg Hobbs

Directions

Empty pitted
water pocket bedrock
slopes to a pool,
dry but expectant,
rims of abandoned
weathered farmsteads
poke between,
follow their middens
through a scattered trail
of broken water vessels,
circle back to the crack
in the center of the earth
smelling of telltale
worn-out depressions,
look to the flash between
the roots of a fast clinging oak
grin the grin of mirror grasses.

(in celebration of Goodman Lake,
Mona Spring and Kristin Kuckelman)

Greg Hobbs
7/21/2010
Water Quality

Laboratory analysis conducted on a water sample from Juárez Spring reveals that, on the basis of those ions comprising at least 10 percent of the total, the water type is calcium/magnesium/sodium-sulfate/bicarbonate. The relatively abundant carbonate ion distribution is consistent with a spring recharge source that moves through the overlying soils which are also high in carbonate (between 15 and 50% maximum content) and is further supported by the presence of carbonate minerals filling surface fractures in the Dakota Sandstone bedrock.

The water quality of Juárez Spring has been characterized by Dr. Robert Weiner as:

**Water Type:** Ca-Mg-Na-SO₄-HCO₃ (Major ions comprising >10% of total)

(Calcium-magnesium-sodium-sulfate-bicarbonate). (See Stiff diagram, Figure XXa.)

**Hardness:** High. At 530, hardness is more than 5 times the threshold at which treatment is recommended, around 70-100mg/L.

**Total Dissolved Solids (TDS):** High. At 910 mg/L, TDS levels are about twice the USEPA’s secondary drinking water standard of 500 mg/L.

**General Assessment of Quality:** With high hardness and high levels of TDS, Juárez Spring water would likely have a stronger taste than treated water. Sulfate levels above 250 (this analysis shows Juárez Spring sulfate at 303 mg/L) may induce intestinal distress in people who are unaccustomed to it, but Goodman Point residents would have developed a tolerance to it. Juárez Spring water has no notable metals contamination, with arsenic, lead and zinc levels being low, and selenium levels being acceptable.
Goodman Point Paleohydrology

For reference, a comparison of Juárez Spring water to United States Environmental Protection Agency (USEPA) drinking water standards is provided in Tables 9 and 10.

Table 9
Juárez Spring Total Metals

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results (mg/L)</th>
<th>EPA Preliminary DW STD (mg/L)</th>
<th>EPA Secondary DW STD (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.10</td>
<td></td>
<td>&lt;0.10</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.0005</td>
<td>0.010</td>
<td>0.0017</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.5</td>
<td></td>
<td>122</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0001</td>
<td>1.3 action level</td>
<td>0.0034</td>
</tr>
<tr>
<td>Iron</td>
<td>0.05</td>
<td></td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Lead</td>
<td>0.0001</td>
<td>0.015 action level</td>
<td>0.0004</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5</td>
<td></td>
<td>56.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.0005</td>
<td></td>
<td>0.0034</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.5</td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.001</td>
<td>0.05</td>
<td>0.023</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.5</td>
<td></td>
<td>92.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.001</td>
<td></td>
<td>0.015</td>
</tr>
<tr>
<td>Hardness as CaCO₃</td>
<td>10</td>
<td></td>
<td>535</td>
</tr>
</tbody>
</table>

Table 10
Juárez Spring Inorganics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results (mg/L)</th>
<th>EPA Secondary DW STD (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity as CaCO₃</td>
<td>286</td>
<td>10</td>
</tr>
<tr>
<td>Bicarbonate as CaCO₃</td>
<td>274</td>
<td>10</td>
</tr>
<tr>
<td>Carbonate as CaCO₃</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Hydroxide as CaCO₃</td>
<td>&lt;10</td>
<td>10</td>
</tr>
<tr>
<td>Chloride</td>
<td>63</td>
<td>10</td>
</tr>
<tr>
<td>pH</td>
<td>8.11 s.u.</td>
<td>NA</td>
</tr>
<tr>
<td>Total-Phosphate</td>
<td>0.24</td>
<td>0.05</td>
</tr>
<tr>
<td>Sulfate</td>
<td>305</td>
<td>10</td>
</tr>
<tr>
<td>TDS</td>
<td>910</td>
<td>10</td>
</tr>
</tbody>
</table>
Goodman Point Paleohydrology

Goodman Point Agriculture

Dryland Farming

Dryland farming is the cultivation of crops, without irrigation, on arid land. Arid land has a low average or highly variable rainfall, where the potential evaporation of water from the land exceeds precipitation (Creswell and Martin 1993). In such regions the ability to produce agricultural crops is restricted and requires the care of a vigilant farmer or carefully selected methods. During the Pueblo III period, most agricultural crops were produced using dryland farming techniques (Lipe and Varien 1999). Dryland farming is used today in the Goodman Point area with relative success, as can be seen in the photo at right. Dryland farming is possible with as little as 10 inches of precipitation a year, but it is more successful with 20 inches or more.

Successful dryland farming depends on numerous factors (Creswell and Martin 1993).

- The use of all available precipitation must be maximized.
  - Evaporation must be minimized.
  - Soil should be conditioned with organic material to help it absorb and hold moisture.
  - Runoff from crop areas must be discouraged.
  - Runoff towards crop areas must be facilitated.
- Quick-growing, drought resistant crops must be grown.
- Wind and heat must not cause excessive evaporation at critical stages of plant growth.
- Soil should be deep with a minimum of clay, sand, or gravel.
- Stubble should be left standing in the field during winter to catch blowing snow.

Modern dryland farmers use many other “tricks” to ensure the success of their crops. To allow the roots to grow deep before the stalk emerges, seeds are planted two to three times deeper than is recommended for irrigated crops. Typically, hardy plants are selected that have natural features for fighting drought, such as waxy
leaves, small leaves, extensive root systems and short life cycles. Although winter wheat is the most common dryland crop in modern times, corn, beans or even watermelons are also grown by skilled present-day dryland farmers.

Modern dryland farmers also try modify sloping fields to keep water from running off. Fields are tilled and planted perpendicular to the slope of the land to create ridges that impede the downhill flow of water. Dryland fields are thoroughly weeded to keep thirsty weeds from competing with desired plants.

**Present-day Farming**

Dryland farming of native grasses, pinto beans and a tall grass crop are cultivated in the surface and geologic drainage area above Juárez Spring. No crops are irrigated within the subject area. Annual average precipitation for the region is approximately 16 inches (as cited in the hypothesis and confirmed with historic records for Yellow Jacket). This appears to be sufficient to sustain the above-mentioned crops; however, it is uncertain to what degree these crops are meeting their full growth potential.

In 2006, the Crow Canyon Archaeological Center began working with traditional farmers from the Hopi Tribe on the “Pueblo Farming Project.” The project aims to study the techniques used by modern Pueblo farmers to gain some insight into ancestral Pueblo practices (Crow Canyon Archaeological Center 2010b).

Preliminary Pueblo Farming Project data have indicated that the dryland growing seasons in shallow canyon bottoms tend to be shorter than those on the canyon rims. This is due to a phenomenon called “cold air drainage,” which refers to the tendency of cool air to settle into lower elevations. Despite the shorter growing seasons in canyon-bottom areas, the Pueblo Farming Project noted that, because of soil moisture retention, these areas are the most productive of the test gardens. This observation is interesting in light of the fact that Crow Canyon archaeologists believe that the ancestral Pueblo people farmed both the valley bottoms and the higher ground. One theory is that this was done to increase the odds of a successful harvest (Bellorado 2008).

In 2009, only two of the Pueblo Farming Project’s five test gardens had measurable yields. The failure of the other three gardens was attributed to “an unusually cool early summer, very dry conditions in the middle of the growing season, and predation by pests, especially grasshoppers” (Varien and Ermigiotti 2009). Similar conditions would have periodically confronted the ancestral Pueblo dryland farmers.

**Ancient Agriculture**

One might think that with an average annual precipitation of only about 16 inches, there was not enough moisture for agriculture at Goodman Point. However, because of the extensive modern practice of dryland farming of beans and hay there, we
know this practice is feasible. The secret to farming at Goodman Point is the high moisture-holding capacity of the deep soil present there.

The ancient people of Goodman Point Pueblo knew how to grow crops for sustenance. Their dryland farming efforts were focused on beans, squash and maize. Maize was introduced to southwest Colorado between 2000 and 1000 B.C. Its production enabled a cultural shift from a hunter/gatherer society to sedentary life.

Before about A.D. 1260, there were scattered pueblos on rolling uplands and abundant agricultural land available. A reasonable estimated ratio of cultivated land to population is one acre per four people. Maize at Goodman Point, for example, may have yielded of about 25 bushels per acre.

In about A.D. 1260, the mesa people in the Goodman Point Pueblo community constructed homes at Goodman Point Pueblo, which encircled Juárez Spring. After about A.D. 1280, when security deteriorated due to raiding, it became difficult to protect the mesas. During this period, the early people would have farmed about 150 to 200 acres, most of it maize.

**Crop Water Needs**

The water needed for crops can be computed using the TR-21 Manual for the Blaney-Criddle Formula (U.S. Department of Agriculture Soil Conservation Service). The water needed is called evapotranspiration of the crop. It is the moisture transpired by the leaves of the vegetation plus that needed for cooling. The computations for evapotranspiration are presented in Table 6.

For maize, the evapotranspiration rate is 19.6 inches for germination through harvesting. A fair crop can be achieved despite a modest water deficiency of 10 to 20 percent. However, in drier years a decline in productivity could be expected.

**Palynology**

The WPI survey of the Goodman Point area showed an abundance of suitable land for dryland farming near the pueblo. A likely cultivation area only 800 feet west of the Pueblo was selected for pollen testing. One soil profile was sampled consisting of three depth horizons to a total of ten inches. The location of the pollen profile sample is 37°24’ 35.89” latitude and -108° 43’ 37.484” longitude, at an elevation of 6,690 feet.

The three samples were bagged and shipped to the Texas A&M University Department of Anthropology Palynology Laboratory. Their technique avoids the use of reagents such as nitric acid and bleach (Holloway 1981). A complete description of the laboratory process is given in Appendix C. Sagebrush and native grasses were defined as the current vegetation from the sample location to help the A&M palynologists distinguish current from historical pollen.
Goodman Point Paleohydrology

The analytic results were interpreted by palynologist Dr. Richard Holloway of Flagstaff, Arizona, who is an expert on southwestern U.S. pollen. Dr. Holloway has performed many pollen analyses for WPI on samples from Mesa Verde National Park. The results of his analysis of samples from Goodman Point are listed in Table 11. The portion of the table above the bold line shows how many grains of each type of pollen were present in each sample, while the numbers below the bold line indicate total pollen concentration. Dr. Holloway’s description follows.

<table>
<thead>
<tr>
<th>Pinus all</th>
<th>P. ponderosa</th>
<th>P. edulis</th>
<th>Juniperus</th>
<th>Salix</th>
<th>Solanaceae</th>
<th>Poaceae</th>
<th>Cheno-am</th>
<th>Asteraceae hs.</th>
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<tbody>
<tr>
<td>GP-A1A</td>
<td>155</td>
<td>17</td>
<td>138</td>
<td>6</td>
<td>0</td>
<td>0</td>
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<td>19</td>
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<td>GP-A1B</td>
<td>67</td>
<td>6</td>
<td>61</td>
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<td>15</td>
</tr>
<tr>
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<td>66</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>1</td>
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</tr>
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<td>4749</td>
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<td>0</td>
<td>206</td>
<td>654</td>
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<td>0</td>
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<td>417</td>
<td>38</td>
<td>32</td>
<td>13</td>
<td>6</td>
<td>234</td>
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</tbody>
</table>

Asteraceae ls | Artemisia | Liguliflorae | Ephedra | Indeterminate | lg tricolpate | Sphaeralcea | Zea mays |
<table>
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<tr>
<th></th>
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<th></th>
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<td>11</td>
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</tr>
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<td>GP-A1C</td>
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<td>33</td>
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<td>GP-A1A</td>
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<td>172</td>
<td>413</td>
<td>0</td>
<td>69</td>
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<td>GP-A1B</td>
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<td>256</td>
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<td>0</td>
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Sample GP-A1A, 0-5 cm. This uppermost sample contained 8879 grains/g total pollen concentration values and was based on a pollen sum of 258 grains, with 4.65 percent indeterminate pollen. Pinus sp. values were high (5334 grains/g) with Pinus edulis type (4749 grains/g) dominant, but with Pinus ponderosa type present in low amounts (585 grains/g). Juniperus pollen (206 grains/g) was high but only a few grains were encountered. Cheno-am pollen was low (654 grains/g) but the assemblage was dominated by high amounts of Poaceae (206 grains/g), High (69 grains/g) and low spine Asteraceae (585 grains/g), Artemisia sp. (1032 grains/g), Liguliflorae (69 grains/g), and Ephedra (172 grains/g). Sphaeralcea and Zea mays pollen were also present (69 grains/g each).

Sample GP-A1B, 5-15 cm. This middle sample contained a total pollen concentration value of 3856 grains/g and was based on a pollen sum of 166 grains with 6.63 percent indeterminate pollen. Pinus pollen (1556 grains/g) was present in moderate amounts but Pinus edulis type (1417 grains/g) still dominated over Pinus ponderosa type (139 grains/g). Juniperus pollen was present in amounts of 70 grains/g which is still high for this taxon. Cheno-am pollen (348 grains/g) was very low but Poaceae (93 grains/g), high (116 grains/g) and low spine (69 grains/g) Astearaceae, Artemisia sp. (511 grains/g), Ephedra sp. (139 grains/g), and Liguliflorae (46 grains/g) were still present in high or very high amounts. A large unknown tricolpate grain was also present in amounts of 23 grains/g but only a single occurrence of this was encountered on the slide.
Sample GP-A1C, 15-25 cm. The deepest sample contained a pollen concentration value of only 1359 grains/g and was based on a pollen sum of 215 grains, with 15.35 percent indeterminate pollen. *Pinus* pollen (442 grains/g) was present in trace amounts with *Pinus edulis* type (417 grains/g) still dominant over the *Pinus ponderosa* type pollen (25 grains/g). *Juniperus* pollen (38 grains/g) was much lower but still relatively high for this taxon. Cheno-am (234 grains/g) and Poaceae (6 grains/g) were present in very low amounts. High (44 grains/g) Spine was moderately high with higher amounts of Low Spine Asteraceae (88 grains/g), moderate to high amounts of *Ephedra* (38 grains/g) and Liguliflorae (32 grains/g) and high amounts of *Artemisia* sp. (177 grains/g). Interestingly, *Salix* (32 grains/g) and Solanaceae (13 grains/g) were present in high to moderate amounts but *Zea mays* (6 grains/g) was present in very low amounts.

The upper sample (A1A) suggests a vegetational community much like that at the present, dominated by *Artemisia* sp. (Sagebrush), and Poaceae (grasses) with Piñon-Juniper Woodland scattered throughout the area. The open sagebrush-grassland community also contained both high and low spine Asteraceae pollen, and other woody components. These are fairly consistent with this type of vegetational community. The concentration values for *Pinus* are consistent with stands of Piñon-Juniper Woodland present throughout the vegetation, although scattered and not a dominant component of the vegetation.

*Pinus* pollen is produced in structures termed strobili, which are located in clusters of 8-10+ on the terminal branch ends. Each strobilus contains approximately 1 million pollen grains specifically adapted to wind pollination. Thus it is reasonable to expect high *Pinus* pollen concentration values from areas where the number of pines is severely reduced or even absent.

The three pollen samples, rather than showing changes in vegetational composition, are interpreted as reflecting increased deterioration to the pollen assemblage as suggested by Hall (1981). In almost all examples, the pollen concentration values reflect a steady decrease in almost all taxa. The area sampled is an open area, not specifically protected by archaeological structures, and as deeper sediments are sampled, the degree of weathering and deterioration increases. This can be seen specifically by the percentage of indeterminate type pollen, which increases with depth.

Thus, assuming that this is indeed the case, the three assemblages, although showing increasing amounts of weathering, are thought to represent a stable vegetational component, probably associated with the occupation of the nearby thirteenth century pueblo.
Remains of Zea mays are present in both the upper and lower levels, suggesting the nearby presence of a potential agricultural field. Several investigations (Jarosz et al. 2003; Raynor et al. 1972) have examined the decrease in corn pollen as one moves away from the cornfield. While Raynor et al. did not use concentration values, Jarosz et al. (2003) compared deposition rates estimated with mass balance and concluded that only a small proportion of the Zea mays pollen would have been airborne more than 30 m downwind of the source. The concentration values of Zea mays pollen from this site strongly argues for an agricultural field in close proximity to this site.

Conclusions on Pollen. The pollen assemblages reveal an increasing degree of weathering associated with the depth of the sample. This is consistent with an exposed, open-air sampling area. The pollen assemblages, however, are all consistent with a sagebrush grassland vegetational component with interspersed areas of piñon-juniper stands. The piñon-juniper component was likely not extensive, as the pollen concentration values decrease dramatically below the uppermost sample. Although at least a portion of this decrease can be attributed to preservation, the assemblages reflect a scattered piñon-juniper vegetation cover rather than a continuous woodland.

Although the pollen concentration values of Zea mays were generally low, this area was a likely location of an agricultural field. The deposition of Zea mays pollen, particularly in the upper sample, suggests that this suspected agricultural field was indeed located in proximity to the pollen sampling area.

Nutrient Yield. The people of Goodman Point Pueblo would have farmed lands near the pueblo. Their main crop was maize with a likely yield of up to 25 bushels per acre.

The nutrient content of maize has been estimated using a yield of about 630 kilograms per acre. This indicates a nutrient value of:

\[
630 \text{ kilograms (kg)/year} \times 16,300 \text{ kilojoules (kJ)/kg} = 10,000,000 \text{ kJ/year}
\]

One acre would tend to support about four people, assuming a caloric requirement of 1,500 per day (6,300 kJ) per person, or 2,300,000 kJ per year. However, the caloric intake of the ancestral Pueblo people would have been supplemented by turkey, beans, squash and wild plants.

Water Use and Handling

The ancestral Pueblo people knew how to harvest and manage water; WPI concluded this from detailed studies of five ancestral Pueblo archaeological sites in Mesa Verde National Park (MVNP) between 1995 and 2007. The Goodman Point residents, like their neighbors on Mesa Verde, benefitted from water handling technology transfer from location to location and from generation to generation. The field evidence at Goodman Point, coupled with lessons learned at Mesa Verde,
Goodman Point Paleohydrology

tells a story of how the water was used and handled. Some conclusions about Goodman Point water use and handling follow:

1. Minimal water needs of the 500 to 800 Goodman Point residents would have been about 600 gallons per day.

2. Water sources included:
   Juárez Spring, 2,800 gallons per day
   Mona Spring (Teal Spring), 700 gallons per day
   Goodman Lake, sporadic supply

3. Juárez Spring was situated in the center of the pueblo. Mona Spring and Goodman Lake are about one-half mile to the southwest and approximately 50 feet higher in elevation. The round-trip walk to Mona Spring and Goodman Lake would take about one-half hour with modest expenditure of energy (depending on their load).

4. Water would have been collected and transported in pottery jars having a capacity of about five to six gallons of water, weighing about 40 to 50 pounds. The jar, itself, would add considerable additional weight, making the load a heavy one.

5. Juárez Spring No. 2 was developed as a structural headworks on the side of the slope where it issues from the bedrock. This location would allow for the direct filling of jars.

6. Juárez Spring No. 1 issues from the base of a six-to-eight-foot-thick sandstone ledge. Here, too, spring headworks would likely have allowed for direct jar filling.

7. Because of their low rates of flow, water collection at the two Juárez Spring issuance points would have been inefficient. Additional jar filling would have occurred at the pools adjacent to the springs. Pools would have been created in the downstream gully to collect and store water from the springs before it was lost to evapotranspiration and seepage.

8. Mona Spring issues from a sandstone outcrop near the bottom of a shallow gully. Here, the likely headworks was a gully-bottom pool.

9. Goodman Lake, with a sporadic water supply, provided stored water from direct rainfall-runoff. Stepping stones in the lake bottom would allow for access to the pooled water for the filling of jars. The ancestral Pueblo people could have walked to Goodman Lake to fill their jars if necessary, helping ensure an adequate supply.
10. During years of low rainfall when the yield of the spring might be diminished, the people could have excavated shallow holes in the gully downstream of the spring to supplement the spring flow. This augmented the supply.

11. Water jars were carried to the individual 13-room blocks and many of the 450 rooms and 114 kivas for domestic use. Bowls for water for the turkeys would be filled; one gallon per day for about four turkeys.

12. No water was used for irrigation; the supply was not adequate for such purposes. The people relied on dryland farming.

13. Water collection and transport was a regular and major operation for the families of Goodman Point, jar filling occurred about 150 times per day under average conditions. This would require a specific time input of roughly 75 person-hours per day.

14. The quality of the water issuing from the sandstone formation was good for its purposes, even with rather high TDS. It was essentially free of harmful organisms, such as bacteria. However, the pooled water adjacent to the springs and in Goodman Lake was susceptible to contamination. Suffering from water-borne organisms would likely have been common.

Other evidence that points to overall Pueblo III water-handling practices at Goodman Point comes from other Pueblo III settlements at nearby Sand Canyon and at Mug House in MVNP. Sand Canyon has been studied extensively by Crow Canyon Archaeological Center and Mug House was studied by WPI, Art Rohn and others. These three Pueblo III communities faced similar water-supply challenges as well as pressure from drought and civil unrest. Stressful scenarios unfolded at all three settlements at about the same time.

Team members Greg and Bobbie Hobbs analyzed water use and handling at Goodman Point from this cultural perspective. Their synopsis was used to develop Appendices A and B; these summaries create a picture of the situation at Goodman Point Pueblo and Sand Canyon Pueblo in the late thirteenth century. The following is excerpted from the Hobbses’ report:

These two sites evidence a concentration of indigenous North American people, who formerly lived in scattered family farmsteads, into larger communities consisting of 500 to 800 individuals. These villages lasted only a short time, from approximately A.D. 1250-1280.

The population in this Mesa Verde/Great Sagebrush plain region, building since 550 A.D., had swelled to approximately 10,000 to 30,000 people. By the final decades of occupation, they depended almost exclusively on stocks of corn and corn-fed domesticated turkeys to weather themselves through cyclical droughts they and their ancestors had experienced.
Each was a rock-walled village that guarded a precious spring. Then, the Great Drought set in. Rain did not fall; groundwater receded. After 1277, both the Goodman Point and Sand Canyon villages suffered fatal attacks. Kuckelman and her fellow researchers discovered the remains of men, women and children killed, apparently, by other Pueblo people foraging for food.

With the corn crop failing and their food stores depleting, the people turned to subsistence living, hunting rabbits, gathering wild plants. Stressed towards starvation, families began migrating south and southeast, to such places as the Rio Grande River pueblos and the canyons and mesas now occupied by Navajo, Hopi and other Pueblo groups.

Ruined towers among the Sand Canyon and Goodman Point ruins, as elsewhere at the head of Hovenweep arroyos, witness the fear of invasion suffered by those who stayed. By 1300, Mesa Verde and the Great Sagebrush plain stood empty and waiting.

“The data from Sand Canyon suggest that an important factor in the depopulation of the village was a collapse of the largely maize and turkey subsistence base that was precipitated by an abrupt climatic downturn; population pressures, long-term environmental degradation, resource depletion, and additional social and environmental factors. . . no doubt exacerbated the impact of this unfavorable climatic shift” (Kuckelman 2010b). “Raising turkeys was costly, however; one average adult turkey drinks 0.5 to 1.0 quart of water per day and eats about 0.5 lb of food per day. Large turkey flocks would have consumed many pounds of maize daily” (Kuckelman 2010b).

When Goodman Point village was built in the mid-1200s, about a half-hour walk through piñons and junipers would have brought them to Goodman Lake if they needed water to supplement Juárez Spring.

**Astronomy at Goodman Point**

The ancestral Pueblo people left us field evidence related to their determination of true north and the orientation of important structures based on solar and lunar alignments. Evidence of deliberate astronomical alignments exists at Mesa Verde, Chaco Canyon, Hovenweep, Sand Canyon, Yellow Jacket and other sites. Dr. J. McKim Malville, an archaeoastronomer, has studied these alignments over many years.

The D-shaped bi-wall at Goodman Point faces south-southeast (SSE) with the SSE face in approximate alignment with the June solstice sunrise as do the bi-wall at
Goodman Point Paleohydrology

Sand Canyon and several of the Great Houses at Chaco Canyon. On the other hand, the alignment of great kivas at Goodman Point and Sand Canyon have a remarkable north-south orientation.

The early people of the Southwest had an uncanny ability related to astronomy. At Goodman Point the work of planning and building included consideration of astronomy. A report by Dr. Malville that explains his field work findings at numerous Southwest archaeological sites is presented in Appendix D.

In Summation

1. Prior to the construction of the Goodman Point village, the ancestral Pueblo people on Goodman Point were settled over 15 to 20 square miles that contained about 20 springs issuing from the Dakota Sandstone. Of these, Juárez Spring was the best; it was reliable and had a good yield.

2. Juárez Spring yielded about two gallons per minute from its two points of issuance.

3. Juárez Spring was generally adequate to support the 500 to 800 residents of the village. Water jars of about five gallons each could be filled and taken to individual residences.

4. During years of low rainfall when the yield of the spring might be diminished, the people could excavate shallow holes in the gully downstream of the spring to supplement the spring flow. They could also walk to Goodman Lake to fill their jars. Therefore, even in dry years, the water supply would have been adequate.

5. The people of Goodman Point Pueblo would have needed about 125 to 200 acres of maize fields. Because of security concerns, the fields would have likely been near the village. There was ample area available for cultivation.

6. The Wetherill soils of Goodman Point are excellent for dryland farming. The soils are deep, with a large water-holding capacity. The infiltration rate is about 0.5 inches per hour, so there is little runoff.

7. The area’s Dakota Sandstone is saturated, but, because of limited fractures and jointing, it supports only low-yielding wells. The Dakota Sandstone is recharged by water percolating down through the Wetherill soils and into the bedrock. Water in the formation is unconfined and flows downgradient by gravity to Juárez Spring (2 gpm) and Mona Spring (0.5 gpm).

8. Goodman Lake was a traditional reservoir of the ancestral Pueblo people that utilized bare bedrock as a watershed. The bedrock surface yielded water to the lake even during minor rainfalls. We estimate that the lake received
about 200,000 gallons of water per year, but this would have dropped to 40,000 gallons in a year of poor rainfall.

9. The water quality of the Goodman Point springs is relatively good. The water has high levels of hardness and total dissolved solids due to percolation through the Wetherill soils. There is no notable metals contamination.

10. Pollen testing demonstrated that maize was grown near Goodman Point Pueblo and that the area was sagebrush grassland with stands of piñon-juniper, but not a continuous woodland.

11. The ancestral Pueblo people understood lunar and solar alignments and true north and used this knowledge in the orientation of some of their structures.

12. The Goodman Point community was viable because of good land and ample water. The residents were good dryland farmers and managers of water.

Goodman Lake was dry in July 2010.
References


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Background

In May 2010 the Wright Paleohydrological Institute (WPI) of Boulder, Colorado was granted authority to analyze the paleohydrology of the Goodman Point Group in Hovenweep National Monument by National Park Service Superintendent Corky Hays. The study was undertaken under ARPA permit No. 05-HOVE-01-ext1 held by the Crow Canyon Archaeological Center. WPI crews performed field studies at Goodman Point on May 15, July 21, July 31, September 11 and December 4, 2010. This report describes the results of WPI’s field work, research and analysis of the paleohydrology of Goodman Point.

Hovenweep National Monument contains the ruins of six Ancestral Puebloan villages in southeast Utah and Southwest Colorado along the shared border. WPI’s study site, Goodman Point, is one of four of Hovenweep’s archaeological sites located in Colorado, along with Holly Canyon, Hackberry Canyon and Cutthroat Castle. The two villages located in Utah are Cajon and Square Tower.

The abandoned structures of Hovenweep were first noted in 1854 by the leader of a Mormon expedition into southeast Utah, W.D. Huntington. Famed Southwest photographer William Henry Jackson named the area "Hovenweep" in 1874 based on a Paiute/Ute word meaning "deserted valley." In 1889, Hovenweep National Monument became the first archaeological site to be protected by the U.S. government (Crow Canyon Archaeological Center 2010). In 1889 W. D. Harlan, a U.S. Surveyor General, was granted his request that an area containing the Goodman Point Unit be reserved from homesteading. In 1918, Smithsonian Institution ethnologist Jesse Fewkes studied the Hovenweep ruins and recommended that the site be further protected. Fewkes’ request was granted in 1923 when President Warren G. Harding designated Hovenweep a unit of the National Park System.

WPI is a non-profit organization dedicated to the study of water use and handling by ancient cultures. Founded in 1996 by Kenneth and Ruth Wright, WPI has undertaken paleohydrological studies at the following sites.

- Morefield Reservoir, Mesa Verde National Park (MVNP)
- Far View Reservoir, MVNP
- Sagebrush Reservoir, MVNP
- Box Elder Reservoir, MVNP
- Mug House Cistern, MVNP
- Machu Picchu, Peru
- Tipon, Peru
- Moray, Peru
- Ollantaytambo, Peru
- Granada, Spain
- Barbegal, France
- Olympia, Greece
- Pompeii, Italy
Goodman Point Paleohydrology

WPI's findings have been reported on in public lectures at many public venues, including the Library of Congress. Many of WPI's reports can be found at: www.wrightpaleo.com.

Acknowledgements

WPI researchers are grateful to the Crow Canyon Archaeological Center and to Corky Hays, Superintendent, Hovenweep National Monument, who authorized WPI to work under Crow Canyon’s archaeological permit. Kristin Kuckelman of Crow Canyon was particularly generous in her oversight, guidance, sharing of information and participation in field visits.

WPI was introduced to Goodman Point when Mesa Verde National Park Assistant Superintendent Betty Janes and her hydrologist husband invited WPI President Kenneth Wright to the archaeological site in 2006. Assistant Superintendent Janes explained the importance of the Goodman Point site for developing an overall understanding of the ancestral Pueblo III people and their struggles during the thirteenth century.

WPI acknowledges and thanks the many volunteers who participated in research and the development of this report.

Part of the team is shown above: Peter Foster, Brendon Langenhuizen, Gary Witt, Ruth Wright, Ken Wright, Bobbie Hobbs and Kristin Kuckelman.
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Appendix A

The Search for Mona Spring

By Justice Greg Hobbs

Reprinted from *The Docket*, November 2010
On-the-ground research archaeologist Kristin Kuckelman has studied the Ancestral Pueblo people of the Southwestern United States for three decades. Working out of Crow Canyon Archaeological Center near Cortez, her most recent investigations have centered on the Sand Canyon and Goodman Point pueblos located within the Canyons of the Ancients National Monument and Hovenweep National Monument, respectively.

These two sites evidence a concentration of indigenous North American people who formerly lived in scattered family farmsteads, moving into larger communities consisting of 500 to 800 individuals. These villages lasted only a short time, from approximately A.D. 1250 to 1280.

The population in this Mesa Verde/Great Sagebrush plain region, building since A.D. 550, had swelled to approximately 10,000 to 30,000. By the final decades of occupation, they depended almost exclusively on stocks of corn and corn-fed domesticated turkeys to sustain themselves through cyclical droughts they and their ancestors had experienced.

Each was a rock-walled village that guarded a precious spring. Then, the Great Drought set in. Rain did not fall; groundwater receded. After 1277, both of these villages suffered fatal attacks.

Goodman Lake, an ancient reservoir in Hovenweep National Monument outside of Cortez, was dry in July.

“Case studies such as this, of ancient societies whose history of choices and decisions ultimately led to untenable relationships with their environment, may provide a cautionary tale to a modern world facing global warming,”


by Justice Greg Hobbs

This is the first of a two-part story on Justice Hobbs’ trek through southwestern Colorado to help survey Ancestral Pueblo water sources. Here, he travels with grandson K.J. and archaeologist Kristin Kuckelman in July.
Kuckelman and her fellow researchers discovered the remains of men, women and children killed, apparently, by other Ancestral Puebloans foraging for food.

With the corn crop failing and their food stores depleting, the people turned to subsistence living, hunting rabbits and gathering wild plants. Stressed toward starvation, families began migrating south and southeast, to such places as the Rio Grande River pueblos and the canyons and mesas now occupied by Navajo, Hopi, and other Ancestral Pueblo groups.

Towers among the Sand Canyon and Goodman Point ruins bore witness to the fears of invasion that those who stayed actually suffered. By about 1280, Mesa Verde and the Great Sagebrush plain stood empty and waiting.

On their way out, the departed ancient ones ritually torched the roofs of their kivas, leaving inside skillfully crafted and decorated pots, intact for a possible return when climes might improve.

“The data from Sand Canyon suggest that an important factor in the depopulation of the village was a collapse of the largely maize and turkey subsistence base that was precipitated by an abrupt climatic downturn; population pressures, long-term environmental degradation, resource depletion, and additional social and environmental factors...no doubt exacerbated the impact of this unfavorable climatic shift,” according to Kuckelman.

She also reports on the high food cost of raising the turkeys they prized because “one average adult turkey drinks .5 to 1 quart of water per day and eats about .5 pounds of food per day. Large turkey flocks would have consumed many pounds of maize daily.”

On July 21, Kuckelman led my grandson, K.J., and me into the Goodman Point Unit of Hovenweep National Monument. There to conduct a preliminary investigation for a larger survey team from the Wright Paleohydrological Institute, we walked through sagebrush and pinyon to water sources the residents depended upon. These include an ancient reservoir, now called Goodman Lake, and two springs, the Mona Spring and the Juarez Spring.

Measuring an acre, capturing...
intermittent stormwater runoff shed from exposed and pitted sandstone cap rock, Goodman Lake was dry.

For all her years of work in this area, Kuckelman had never seen Mona Spring. We went looking for it.

We tracked past the ruins of small farmsteads, occupied likely centuries earlier than the Goodman Point Pueblo. Inhaling the smell of native water-loving grasses, we dropped into an arroyo, flashing green, and followed it up through a series of dried-up pools, where the people must have kneeled with their large water-bearing pots, no doubt adorned with beautifully painted stripes and zigzags.

Kuckelman beamed when we found the Mona Spring, a perfect mirror pool sheltered under a prominent ledge, hosting a very happy and sturdy live oak. In celebration of our walk, I write:

Directions

Empty pitted water pocket bedrock slopes to a pool, dry but expectant,

rims of abandoned weathered farmsteads poke between pinyon,

follow their middens through a scattered trail of broken water vessels,

circle back to the crack in the center of the earth smelling of telltale worn-out depressions,

look to the flash between the roots of a fast-clinging oak grin the grin of mirror grasses.

On the trail into the Goodman Point community, we pass through the breached guardian wall surrounding the village to the large rock overhang of Juarez Spring. What a gathering place, a natural plaza of goodly proportion where the people drawing water must have worked and talked, their children playing. When the fatal attack came, they fought to hold on.

On July 31, when the main Wright survey party joined Kückelman, monsoon rains had broken a dry spell. Goodman Lake glistened.

K.J. and I were traveling on to Canyon de Chelly for a workshop with the Navajo Teachers; the Hopi Mesas, spotting Old Oraibi in the distance and attending a Kachina going-home rain dance close up at Hotevilla; then to the Colorado River for a run through the Grand Canyon with Hatch River Expeditions.

Everywhere, on sandstone slabs and jutting promontories, we see Ancestral Puebloan handprints and creation panels, replete with mountain sheep, spiraling springs, and Kokopellis.
Appendix B

A Perfect Point: Springs and Reservoir Connect the Past with the Present

By Justice Greg Hobbs

Reprinted from The Docket, December 2010
Read the first part of this story, “The Search for Mona Spring,” online at denbar.org/docket.

This is the second of a two-part story on Justice Hobbs’ trek through southwestern Colorado to help survey Ancestral Pueblo water sources. Here, he travels with his wife Bobbie, the Wright Paleohydrological Survey team, and archaeologist Kristin Kuckelman of the Crow Canyon Archaeological Center.

By Justice Greg Hobbs

Senior archaeologist Kristin Kuckelman leads us back into the Goodman Point Unit of Hovenweep National Monument in southwestern Colorado on Sept. 11. My wife Bobbie and I are here with the Wright Paleohydrological Institute team to survey Ancestral Pueblo water sources.

Ken and Ruth Wright welcome us at a stopping point on County Road P, northwest of Cortez. It’s a quarter to eight a.m. this memorial day of the day of the 2001 assault on the Twin Towers. It is one of those high-pressure sky-is-blazing blue, end-of-summer golden days of incipient fall! Sleeping Ute Mountain looms immediately to the south. In the midst of the great drought of the late 1270s, attackers from other Pueblo settlements destroyed the Goodman Point village we are about to enter.

You can’t miss the rendezvous place. A couple of Corgi greeter dogs belonging to a family on the north side have taken possession of the road’s centerline. Legend of Southwestern archaeology David Breternitz and his wife Barbara arrive to a good double-wag sniffing. Pete Foster, Gary Witt, and Brendon Langenhuizen unpack from their trucks an array of survey, flow, and water quality measurement devices.

Ken previously e-mailed the day’s investigatory hypothesis:

Juárez Spring Hypothesis—Goodman Point

The partially saturated Dakota/Burro Canyon formation north and west of the Goodman Point Juárez Spring drains by gravity at the rate of about three acre-feet (3,700 cubic meters) per year to the spring. Occasionally, localized precipitation doubles the two-gallon-per-minute (7.6-liter-per-minute) spring flow. With 1 percent of the annual precipitation reaching the groundwater reservoir, the likely geologic tributary area is 290 acres (1.2 square kilometers).

I translate the problem like this: Flow from the springs of Mesa Verde and the Great Sagebrush plain underpinned the people’s viability. The population had grown to between 10,000 and 30,000 people. Why? Good food supply? Better health? More migration to the area? More frequent rains? After nearly 800 years of occupation, they aggregated around A.D. 1250 from individual farmsteads into villages of 500 to 800 people. They surrounded their precious...
springs with guardian walls.

Data gathering must ground our understanding of who they were, how they lived, and how – maybe why – they departed. The sciences of archaeology and paleo-hydrology have their methods and their limitations.

It's the people's art that awes us most. Their D-shaped structures containing rooms and kivas, their surroundings, and their towers—practical, beautiful, defensive—testify to their beliefs, their tenacity, and their fears.

We can only talk with them through what they left. Our tentative conclusions, supported by demonstrable facts, must necessarily adapt to findings that will certainly come after us.

So, here we go on the trail! The routed wooden National Park Service sign reads:

Hovenweep
National Monument
Goodman Point Group
143.3 acres
Protected by Nat'l Park Service

“Protected” is relative to what has happened in the settlement of this part of the Four Corners region. In the early 1880s, as Anglo homesteaders moved in, some omniscient government work resulted in reserving a portion of the archaeological wonders residing here. All around, the chaining of trees and the plowing of fields for hay, beans, and homes resulted in dumping many ruins into choked arroyos. Salvaged treasures, such as whole painted water jugs and perfect arrow points, were taken from this region and appear in public museums and private homes throughout the world.

Ken distributes topographical maps. The Goodman Point Unit is bifurcated by a tract of private land the government ceded back for contemporary settlement in the 1950s. Accordingly, Goodman Point village and Juárez Spring lie north of the private tract; Goodman Lake and Mona Spring are south of no-trespassing wires.

Goodman Lake, named for an 1870s Anglo cattle company foreman, is an Ancestral Pueblo reservoir located, like nearby Mona Spring, on Bureau of Land Management (BLM) property. Under permit by the National Park Service and BLM to Crow Canyon Archaeological Center, we conduct our water survey under the auspices of Kristin Kuckelman. Her research in this area dates back to the late 1970s, when she worked alongside Breternitz and others prior to construction of the Bureau of Reclamation’s Dolores water project.

With the Breternitzes anchoring our orientation point on the sandstone ledge above Juárez Spring, we climb down through the collapsed guardian wall that encircled the village. We skirt many sunken kiva mounds, terraced one atop the other, on the arroyo's steep side slope.

Sleeping Ute to the south, Mesa Verde to the southeast, and the La Plata Mountains to the east. These are the views the people enjoyed, as do we.

We fight our way through guardian willows to the second Juárez Spring discharge point; the first is dry. Pete, Brendon, and Gary take water measurements using a mobile weir. A comparison of flow rates between morning and afternoon for nearby springs shows daily variation, the consequence of willows taking their fill in the afternoon heat. Always observant, the people must have queued to fill their water jugs early in the day. I write:

Willow

You've got to respect the willow.

In the heat of the day, they’ll drink a good long draw.

Fill your water jug early, the willow will shade your hot afternoon.

This way you can drink each others’ company.

Kristin appears directly above on the damp side slope. It’s good to see and be with her again. She says the people also may have intercepted water from this spring higher up the slope near their homes.

Throughout the Four Corners region, the Ancestral Pueblo people built berms, check dams, reservoirs, and steps into scooped-out pools wherever water might appear, or be found, by digging into a high water table for drinking water. They were dryland corn and domestic turkey farmers. All they had were wood and stone digging sticks tied together with plant fiber, baskets, pots, and animal bone for marshalling drinking water and dredging out sediment. The oldest water works discovered to date in the southwest are twenty 12,000-year-old hand-dug wells near Clovis, N. M.

Pete, Brendon, Gary, Kristin, Bobbie, and I take the two trucks around the private land to a gate along the BLM fence line. Shouldering up the water testing equipment, Kristin and I lead our group down the grass-high arroyo to Mona Spring. We located the spring on July 21, with my grandson K.J.

Archaeologist Kristin Kuckelman, Bobbie Hobbs, and Wright Paleohydrological Institute team member Brendon Langenhuizen cup water into the pitted cap rock to determine the spillover amount for an ancient reservoir fill.
during our preliminary investigation.

This time, we bow under the rocky ledge alcove from which the spring apparently issues. The sandstone walls are damp and green. Mineralized calcium carbonate mushroom-like wafers dot the drip line. We cannot find anything like the steady stream we saw at Juárez Spring. Seeps are more like it here.

Kristin pushes back tall grasses growing on the upslope side of Mona Spring’s pool. She finds rocks that look like steps for filling water jars. The people must have stooped to ladle water into the jugs. Brendon and Pete take water quality samples for lab testing.

We cross the exposed cap rock straight east to Goodman Lake. Water-loving reeds are growing throughout the reservoir, which glistens in the sun. On July 21, we saw dead grass only. A healthy dose of “monsoon” rain has moved across the pitted watershed rock into the capture zone the Ancestral Puebloans created.

Brendon and Pete conduct an infiltration test on the dam by timing the movement from a tube of water into the compacted soil. The water penetrates very slowly. It’s a good and tight water collecting structure the people built.

Settlers of the 1880s may have dredged the reservoir body and elevated the dam. When asked, they said the reservoir was there when they got there. They hauled household water out of here by horse and wagon.

On the hill above the reservoir on the south ridgeline toward Mona Spring are the remnants of five Pueblo-II farmsteads. Based on pottery shards lying about, the people likely lived here between A.D. 1000 and 1150.

They built the reservoir and could have used it conjunctively with Mona Spring. Due to lag time between recharge and discharge, the Mona Spring pool could have provided water in drought times. As the spring faltered, when rains returned, the reservoir would catch the cap rock run-off from intermittent storm. On the southwestern side of the reservoir below the ancient farmsteads, Bobbie sees stones in the grasses that may have been stepping stones for filling water jars.

When Goodman Point village was built in the mid-1200s, probably not more than a half-hour walk through pinyons and junipers, it would have brought them to the reservoir if they needed water to supplement Juárez Spring.

Kristin and I explore the fence line between the BLM and private land. The private property has been cleared for farming and grazing. A rough road we cannot cross runs along the private side of the fence. We try to spot where the path from Goodman Point Village might have passed through to Goodman Lake. Though we see a couple of likely possibilities, we cannot be sure.

Kristin goes back to the survey work on the reservoir. I walk the entire length of the fence line east to where it stops at the corner of the Park Service/BLM boundaries. I stumble my way through the brush and two arroyos there and back. Obviously, this is not a trail the people would have taken back and forth to Goodman Lake.

They would have travelled more easily across the higher ground through what is now the private property. Kristin has marked their probable route on the contours of a topo map. Two trails—one from the Shields Pueblo and one from Goodman Pueblo—still intersect at a point on the Park Service property abbreviated by the no-trespassing wires. I bet the path was close to straight across from this intersect, south to the watershed cap rock that feeds Goodman Lake.

The rest of the afternoon we survey the water shedding capacity of the cap rock into the reservoir. Brendon relies on Kristin, Bobbie and me to help. Bobbie holds and moves a long, gauged rod. Brendon sights through the tripod surveying instrument. Kristin draws out bucketfuls of water from the reservoir. All of us cup out and pour the bucket water into the folds and pockets of the cap rock.

Brendon has tape-measured out a 100-square-foot trapezoidal area from which to calculate the water retaining capacity of pitted rock. When we finish pouring a total of 6.7 gallons of water into the spaces, he figures it would take more than a tenth of an inch of rain to fill the voids in the cap rock and begin spilling into the reservoir.

I calculate Brendon a smart young man.

We rendezvous with Ken and Ruth, who have spent the afternoon exploring for Dakota Formation outcrops and knocking on neighbors’ doors throughout the area to gather well water levels. The people now living here report hauling water for decades. They didn’t like the taste of the mineralized water in the shallow groundwater formation that feeds Juárez and Mona springs. Some of the wells went dry and the good ones gave only low yields. Now, a rural water utility has extended Dolores Project water to their kitchen sinks and toilets. The Ancestral Pueblo people did with what they had.

During the day, Kristin finds a perfect arrow point, more than 1,000 years old, lying on the ground beside a collapsed Ancestral Pueblo dwelling. She holds it flat and open on the time lines of the palm of her left hand. I snap a photo. A perfect point. She returns this precious artifact to the centuries, right where she found it.

Endnote: My narration of this two-part article greatly benefits from field conversations with Kristin Kuckelman and articles and reports by her and her colleagues at Crow Canyon Archaeological Center.
Appendix C

Pollen Analyses of Sediments from Goodman Point, Hovenweep National Park, Montezuma County, Colorado

By Richard G. Holloway, Ph.D.

Quaternary Services Technical Report Series
Pollen Analysis of Sediments from Goodman Point, Hovenweep National Park, Montezuma County, Colorado

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Introduction

A total of 3 soil samples were sent for extraction and analysis to Quaternary Services. The samples were taken from a suspected agricultural field near a 13th Century Pueblo near Goodman Point within Hovenweep National Monument, Montezuma County, Colorado. The sampling location was given as 37° 24' 35.89" N. Lat and 108° 43' 37.484 W Long, within the Wetherill Loam soils, at approximately 6690' AMSL. The site is located due west of an intermittent stream which is approximately 100' lower in elevation. While the 13th Century Pueblo is close, no location for this Pueblo was provided. The modern vegetation is dominated by Artemisia sp. and various grasses along with intermittent Piñon-Juniper Woodland.

Methods and Materials

Chemical extraction of pollen samples was conducted at the Palynology Laboratory at Texas A&M University, using a procedure designed for semi-arid Southwestern sediments. The method, detailed below, specifically avoids use of such reagents as nitric acid and bleach, which have been demonstrated experimentally to be destructive to pollen grains (Holloway 1981).

From each pollen sample submitted, 20 grams (g) of soil were sub-sampled. Prior to chemical extraction, two tablets of concentrated Lycopodium spores (batch #307862, Department of Quaternary Geology, Lund, Sweden; 18,563 ± 500 marker grains per tablet) were added to each sub-sample. The addition of marker grains permits calculation of pollen concentration values and provides an indicator for accidental destruction of pollen during the laboratory procedure.

The samples were treated with 3 percent Hydrochloric Acid (HCl) overnight to remove carbonates and to release the Lycopodium spores from their matrix. After neutralizing the acid with distilled water, the samples were allowed to settle for a period of at least three hours before the supernatant liquid was carefully poured off and discarded. Additional distilled water was added to the supernatant, and the mixture was swirled and then allowed to settle for 10 seconds. The liquid was then carefully poured off and saved in a second beaker. This procedure was repeated a total of three times to ensure that all pollen would be freed from the matrix that remained in the original beaker. The sand and small rocks remaining in the beaker were then discarded. If any clay particles remained in the matrix, the matrix material was placed into a 50 ml centrifuge tube, a solution of Darvan (a detergent) was added and the tube was sonicated in a Delta D-9 Sonicator for no longer than 15 seconds because occasionally, longer sonication can damage some of the most fragile pollen grains. After sonication, the contents of the centrifuge tube were placed in a beaker and the decanting process was repeated three times. We have found that a short sonication will disperse small clods of clay, thus releasing any potential pollen into suspension. All of the saved, suspended fine fraction was decanted through a screen with openings of 150µ. All material passing through the screen was concentrated using centrifugation mesh screen into a second beaker. This procedure, repeated at least three times,
removed lighter materials, including pollen grains, from the heavier fractions.

The fine fraction was treated with concentrated (48%) Hydrofluoric Acid (HF) overnight to remove silicates. After completely neutralizing the acid with distilled water, the samples were treated with a concentrated wash of HCl. This procedure removed any potential fluoro silicates that often form during the HF process. The HCl wash was repeated several times until the solution remained clear after centrifugation. The samples were then washed twice in distilled water.

The samples were dehydrated in glacial acetic acid in preparation for acetolysis. Acetolysis solution (acetic anhydride: concentrated sulfuric acid in 9:1 ratio) following Erdtman (1960), was added to each sample. Centrifuge tubes containing the solution were heated in a heating block at 180° F for approximately 8 minutes, and then cooled for an additional 8 minutes before centrifugation. Each sample was then washed and removal of the acetolysis solution with glacial acetic acid followed by two washes with distilled water. Centrifugation at 2,000 RPM for 90 seconds dramatically reduced the size of the sample, yet from periodic examination of the residue, did not remove fossil palynomorphs. The samples were dehydrated in glacial acetic acid in preparation for acetolysis. Acetolysis solution (acetic anhydride: concentrated sulfuric acid in 9:1 ratio) following Erdtman (1960), was added to each sample. Centrifuge tubes containing the solution were heated in a boiling water bath for approximately 8 minutes and then cooled for an additional 8 minutes before centrifugation and removal of the acetolysis solution with glacial acetic acid followed by distilled water. Centrifugation at 2,000 RPM for 90 seconds dramatically reduced the size of the sample, yet from periodic examination of the residue, did not remove fossil palynomorphs.

Heavy density separation ensued using zinc bromide (ZnBr₂), with a specific gravity of 2.00, to remove much of the remaining detritus from the sample pollen. After 10 minutes of centrifugation at 2,000 RPMs, the light fraction was removed and diluted with 95% ETOH in a ratio of distilled water (10:1) and then concentrated by centrifugation. The samples were then washed repeatedly in distilled water until neutral. The residues were then rinsed in a 5% solution of potassium hydroxide (KOH) for less than one minute which is effective in removing the majority of the unwanted alkaline soluble humates. This was followed by a wash with concentrated HCl, which is essential to remove the remaining dissolved materials that are not water soluble. Next, the samples were washed with distilled water. That process was repeated until the solution was clear.

Although all of the previous procedures will effectively remove most of the unwanted matrix materials, none of these actions seem to have much effect on charcoal, which is inert. Unfortunately, we have yet to discover any procedure that will effectively remove charcoal from pollen samples without harming either the fossil pollen or removing some of it as well.
The residues were rinsed in Ethanol (ETOH) stained with safranin-O, rinsed twice with ETOH, and transferred to 1-dram vials with ETOH. The samples were mixed with a small quantity of glycerine and allowed to stand overnight for evaporation of the remaining ETOH. The storage vials were capped and were returned to Wright Water Engineers Inc. at the completion of the project.

A drop of the polliniferous residue was mounted on a microscope slide for examination under an 18 X 18 mm cover slip sealed with fingernail polish. The slide was examined using 200X or 100X magnification under an aus-Jena Laboval 4 compound microscope. Occasionally, pollen grains were examined using either 400X or 1,000X oil immersion to obtain a positive identification to either the family or genus level.

Abbreviated microscopy was performed on each sample in which either 20 percent of the slide (approximately four transects at 200X magnification) or a minimum of 50 marker grains were counted. If warranted, full counts were conducted by counting to a minimum of 200 fossil grains. Regardless of which method was used, the uncounted portion of each slide was completely scanned at a magnification of 100X for larger grains of cultivated plants such as *Zea mays* and *Cucurbita*, two types of Cactus (Platyopuntia and Cylindropuntia), and other large pollen types such as members of the Malvaceae, or Nyctaginaceae families.

For those samples warranting full microscopy, a minimum of 200 pollen grains per sample were counted as suggested by Barkley (1934), which allows the analyst to inventory the most common taxa present in the sample. All transects were counted completely (Brookes and Thomas 1967), resulting in various numbers of grains counted beyond 200. Pollen taxa encountered on the uncounted portion of the slide during the low magnification scan are tabulated separately.

Total pollen concentration values were computed for all taxa. In addition, the percentage of Indeterminate pollen was also computed. Statistically, pollen concentration values provide a more reliable estimate of species composition within the assemblage. Traditionally, results have been presented by relative frequencies (percentages) where the abundance of each taxon is expressed in relation to the total pollen sum (200+ grains) per sample. With this method, rare pollen types tend to constitute less than 1 percent of the total assemblage. Pollen concentration values, provide a more precise measurement of the abundance of even these rare types. The pollen data are reported here as pollen concentration values using the following formula:
\[
PC = K \times \frac{\Sigma_p}{\Sigma_L \times S}
\]

Where:
- \(PC\) = Pollen Concentration
- \(K\) = Lycopodium spores added
- \(\Sigma_p\) = Fossil pollen counted
- \(\Sigma_L\) = Lycopodium spores counted
- \(S\) = Sediment weight

The following example should clarify this approach. Taxon X may be represented by a total of 10 grains (1 percent) in a sample consisting of 1,000 grains, and by 100 grains (1 percent) in a second sample consisting of 10,000 grains. Taxon X is 1 percent of each sample, but the difference in actual occurrence of the taxon is obscured when pollen frequencies are used. The use of "pollen concentration values" are preferred because it accentuates the variability between samples in the occurrence of the taxon. The variability, therefore, is more readily interpretable when comparing cultural activity to noncultural distribution of the pollen rain.

Variability in pollen concentration values can also be attributed to deterioration of the grains through natural processes. In his study of sediment samples collected from a rock shelter, Hall (1981) developed the "1000 grains/g" rule to assess the degree of pollen destruction. This approach has been used by many palynologists working in other contexts as a guide to determine the degree of preservation of a pollen assemblage and, ultimately, to aid in the selection of samples to be examined in greater detail. According to Hall (1981), a pollen concentration value below 1000 grains/gm indicates that forces of degradation may have severely altered the original assemblage. However, a pollen concentration value of fewer than 1000 grains/g can indicate the restriction of the natural pollen rain. Samples from pit structures or floors within enclosed rooms, for example, often yield pollen concentration values below 1000 grains/g.

Pollen degradation also modifies the pollen assemblage because pollen grains of different taxa degrade at variable rates (Holloway 1981, 1989; Holloway and Bryant 1983). Some taxa are more resistant to deterioration than others and remain in assemblages after other types have deteriorated completely. Many commonly occurring taxa degrade beyond recognition in only a short time. For example, most (ca. 70 percent) Angiosperm pollen has either tricolpate (three furrows) or tricolporate (three furrows each with pores) morphology. Because surfaces erode rather easily, once deteriorated, these grains tend to resemble each other and are not readily distinguishable. Other pollen types (e.g. Cheno-am) are so distinctive that they remain identifiable even when almost completely degraded.
Pollen grains were identified to the lowest taxonomic level whenever possible. The majority of these identifications conformed to existing levels of taxonomy with a few exceptions. For example, Cheno-am is an artificial, pollen morphological category which includes pollen of the family Chenopodiaceae (goosefoot) and the genus *Amaranthus* (pigweed) which are indistinguishable from each other (Martin 1963). All members are wind pollinated (anemophilous) and produce very large quantities of pollen. In many sediment samples from the American Southwest, this taxon often dominates the assemblage.

Pollen of the Asteraceae (Sunflower) family was divided into four groups. The high spine and low spine groups were identified on the basis of spine length. High spine Asteraceae contains those grains with spine length greater than or equal to 2.5µ while the low spine group have spines less than 2.5µ in length (Bryant 1969; Martin 1963). *Artemisia* pollen is identifiable to the genus level because of its unique morphology of a double tectum in the mesocopia (between furrows) region of the pollen grain. Pollen grains of the Liguliflorae are also distinguished by their fenestrate morphology. Grains of this type are restricted to the tribe Cichoreae which includes such genera as *Taraxacum* (dandelion) and *Lactuca* (lettuce).

Pollen of the Poaceae (Grass) family are generally indistinguishable below the family level, with the single exception of *Zea mays*, identifiable by its large size (ca 80µ), relatively large pore annulus, and the internal morphology of the exine. All members of the family contain a single pore, are spherical, and have simple wall architecture. Identification of non-corn pollen is dependent on the presence of the single pore. Only complete or fragmented grains containing this pore were tabulated as members of the Poaceae.

Clumps of four or more pollen grains (anther fragments) were tabulated as single grains to avoid skewing the counts. Clumps of pollen grains (anther fragments) from archaeological contexts are interpreted as evidence for the presence of flowers at the sampling locale (Bohrer 1981). This enables the analyst to infer possible human behavior.

Finally, pollen grains in the final stages of disintegration but retaining identifiable features, such as furrows, pores, complex wall architecture, or a combination of these attributes, were assigned to the Indeterminate category. The potential exists to miss counting pollen grains without identifiable characteristics. For example, a grain that is so severely deteriorated that no distinguishing features exist, closely resembles many spores. Pollen grains and spores are similar both in size and are composed of the same material (Sporopollenin). So that spores are not counted as deteriorated pollen, only those grains containing identifiable pollen characteristics are assigned to the Indeterminate category. Thus, the Indeterminate category contains a minimum estimate of degradation for any assemblage. If the percentage of Indeterminate pollen is between 10 and 20 percent, relatively poor preservation of the
assemblage is indicated, whereas Indeterminate pollen in excess of 20 percent indicates severe deterioration to the assemblage.

In those samples where the total pollen concentration values are approximately at or below 1000 grains/g, and the percentage of Indeterminate pollen is 20 percent or greater, counting was terminated at the completion of the abbreviated microscopy phase. In some cases, the assemblage was so deteriorated that only a small number of taxa remained. Statistically, the concentration values may have exceeded 1000 grains/gm. If the species diversity was low (generally these samples contained only pine, Cheno-am, members of the Asteraceae (Sunflower) family and Indeterminate category, counting was also terminated after abbreviated microscopy even if the pollen concentration values slightly exceeded 1000 grains/g.

Results

Results are presented in Table 1. The individual sample results are presented below.

Sample GP-A1A, 0-5 cm

This uppermost sample contained 8879 grains/g total pollen concentration values and was based on a pollen sum of 258 grains, with 4.65 percent Indeterminate pollen. *Pinus* sp. values were high (5443 grains/g) with *Pinus edulis* type (4749 grains/g) dominant, but with *Pinus ponderosa* type present in low amounts (585 grains/g). *Juniperus* pollen (206 grains/g) was high but only a few grains were encountered. Cheno-am pollen was low (654 grains/g) but the assemblage was dominated by high amounts of Poaceae (206 grains/g), High (69 grains/g) and low spine Asteraceae (585 grains/g), *Artemisia* sp. (1022 grains/g), *Ephedra* (172 grains/g). *Sphaeralcea* and *Zea mays* pollen were also present (69 grains/g each).

Sample GP-A1B, 5-15 cm

This middle sample contained a total pollen concentration value of 3856 grains/g and was based on a pollen sum of 166 grains with 6.63 percent indeterminate pollen. *Pinus* pollen (1556 grains/g) was present in moderate amounts but *Pinus edulis* type (1417 grains/g) still dominated over *Pinus ponderosa* type (139 grains/g). *Juniperus* pollen was present in amounts of 70 grains/g which is still high for this taxon. Cheno-am pollen (348 grains/g) was very low but Poaceae (93 grains/g) high (116 grains/g), and low Spine (697 grains/g) Asteraceae, *Artemisia* sp. (511 grains/g), *Ephedra* sp. (139 grains/g), and Liguliflorae (46 grains/g) were still present in high or very high amounts. A large unknown tricolpate grain was also present in amounts of 23 grains/g but only a single occurrence of this was encountered on the slide.
Sample GP-A1C, 15-25 cm

The deepest sample contained a pollen concentration value of only 1359 grains/g and was based on a pollen sum of 215 grains, with 15.35 percent Indeterminate Pollen. *Pinus* pollen (442 grains/g) was present in trace amounts with *Pinus edulis* type (417 grains/g) still dominant over the *Pinus ponderosa* type pollen (25 grains/g). *Juniperus* pollen (38 grains/g) was much lower but still relatively high for this taxon. Cheno-am (234 grains/g) and Poaceae (6 grains/g) were present in very low amounts. High (44 grains/g) Spine was moderately high with higher amounts of Low Spine Asteraceae (88 grains/g), moderate to high amounts of *Ephedra* (38 grains/g) and Liguliflorae (32 grains/g) and high amounts of *Artemisia* sp. (177 grains/g). Interestingly, *Salix* (32 grains/g) and Solanaceae (13 grains/g) were present in high to moderate amounts but *Zea mays* (6 grains/g) was present in very low amounts.

Discussion

The upper sample (A1A) suggests a vegetational community much like that at the present, dominated by *Artemisia* sp. (Sagebrush), and Poaceae (grasses) with Piñon-Juniper Woodland scattered throughout the area. The open sagebrush-grassland community also contained both high and low spine Asteraceae pollen, and other woody components. These are fairly consistent with this type of vegetational community. The concentration values for *Pinus* are consistent with stands of Piñon-Juniper Woodland present, throughout the vegetation, although scattered, not a dominant component of the vegetation.

*Pinus* pollen is produced in structures termed strobili, which are located in clusters of 8-10+ on the terminal branch ends. Each strobilus contains approximately 1 million pollen grains specifically adapted to wind pollination. Thus it is reasonable to expect high *Pinus* pollen concentration values from areas where the number of pines is severely reduced or even absent.

The three pollen samples, rather than showing changes in vegetational composition, are interpreted as reflecting increased deterioration to the pollen assemblage as suggested by Hall (1981). In almost all examples, the pollen concentration values reflect a steady decrease in almost all taxa. The area sampled is an open area, not specifically protected by archaeological structures etc. and as deeper sediments are sampled, the degree of weathering and deterioration increases. This can be seen specifically by the percentage of Indeterminate type pollen, which increases with depth.
Thus, assuming that this is indeed the case, the three assemblages, although showing increasing amounts of weathering, are thought to represent a stable vegetational component, probably associated with the occupation of the nearby 13th Century Pueblo.

Remains of *Zea mays*, are present in both the upper and lower levels, suggesting the nearby presence of a potential agricultural field. Several investigations (Raynor et al. 1972; Jarosz et al. 2003) have examined the decrease in corn pollen as one moves away from the cornfield. While Raynor et al. did not use concentration values, Jarosz et al (2003) compared deposition rates estimated with mass balance and concluded that only a small proportion of the *Zea mays* pollen would have been airborne more than 30m from distance downwind of the source. The concentration values of *Zea mays* pollen from this site strongly argues for an agricultural field in close proximity to this site.

Based on the pollen taxa recovered, the question always arises are economic taxa absent from these assemblages because they are truly not present, or, are they present in such small amounts to have been missed during sampling. In order to assess the likelihood of their being missed, the estimated maximum potential concentration values of target taxa was computed. Since the entire slide was examined (either by count or low magnification scan of the slide) the estimated number of marker grains per slide was computed by averaging the number of marker grains per transect and multiplying this by the total number of transects examined. Assuming, that the first grain observed on an hypothetical second slide was one of the target taxa, the maximum potential concentration value can be computed. Thus, the number of the fossil grains is one, and the number of marker grains per slide is substituted for the number of marker grains counted in the pollen concentration formula. These data are presented in Table 1 and indicate that the estimated potential pollen concentration values fall between 34.0 and 6.0 grains/g. Without examining the total of the pollen residues we can never be absolutely sure that target taxa are indeed absent from the assemblage. The concentration values were much higher for the upper 2 samples which accounted for the higher estimated maximum potential concentration values. In spite of these relatively high values in the upper 2 samples and the much lower values in sample A1C, I that it is more likely that the missing taxa were indeed absent from these assemblages. In this particular case, however, it is possible that additional economic taxa were in such low amounts as to be missed during counting.

Conclusions

The pollen assemblages reveal an increasing degree of weathering associated with the depth of the sample. This is consistent with an exposed, open-air sampling area. The pollen assemblages however, are all consistent with a sagebrush grassland vegetational component with interspersed areas of Piñon-Juniper stands. The Piñon-Juniper component was likely not extensive as the pollen concentration values
decrease dramatically below the uppermost sample. While at least a portion of this decrease can be attributed to preservation, I feel that these assemblages reflect more a scattered Piñon-Juniper vegetation cover rather than a more continuous woodland.

While the pollen concentration values of *Zea mays* were generally low, this area was likely the source for an agricultural field. The deposition of *Zea mays* pollen, particularly in the upper sample, suggests that this suspected agricultural field was indeed located in fairly close proximity to the pollen sampling area.
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Table 1: Results of Pollen Analysis, Goodman Point, Hovenweep National Monument

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Goodman Point Samples
Appendix D

Astronomy and Abandonment in the Pueblo III World

By J. McKim Malville, Ph.D.
Astronomy and Abandonment in the Pueblo III World

Dr. J. McKim Malville

In the latter half of the 13th Century, life was getting very difficult throughout the ancestral Pueblo world. The climate was getting drier and colder, and crops were failing. Famine and competition for scarce resources led to social instability and violence. The isolated towers of Hovenweep were one response to these threats. Another approach was followed by the residents of Sand Canyon and Goodman Point who built their villages in defensible locations next to water sources, surrounded by protective walls. Isolated homesteads, once the norm in the Northern San Juan, were abandoned as people aggregated into these more secure villages. The large community of Yellow Jacket had no such defensible wall, but towers were built on its northeastern edge probably to guard the spring and protect residents; its Great Tower was constructed in A.D. 1254 at the start of this turbulent period.

Solar Ceremonies in Mesa Verde

The cliff enclosures of Mesa Verde provided superb opportunities for protection from attack. Most contained seeps or spring in their back walls, allowing the residents to survive prolonged sieges. Even though defense may have been uppermost in the minds of the residents of the Cliff and Fewkes Canyons in Mesa Verde, ceremonies at Cliff Palace and the Sun Temple involving the sun and moon must have been vital features of community life. The first astronomical ceremonies held on the mesa between Cliff and Fewkes Canyons in Mesa Verde probably involved the eroded rock at the southwest corner of the Sun Temple. Even before
construction of the Sun Temple and Cliff Palace structures, that rock may have been the location for a summer solstice celebration. A celebrant standing next to the stone would have seen the summer solstice sun rising over the enclosure of Cliff Palace. At that time there would have been the juxtaposition of the dark cave, perhaps representing the place of emergence, with the brilliant sun at the moment of its birth.

![Cliff Palace of Mesa Verde. People are standing in line to view the pictographs inside the four-story tower.](image)

Cliff Palace faces to the southwest and receives little sunlight during summer solstice. For its residents, eager to receive heat from the sun in a winter afternoon, the greatest amount of sunlight and solar heating would occur during the coldest months. It is an auspicious coincidence that the sun rock is located approximately at the place on the horizon where the sun would set at winter solstice.

At the extreme southern end of the Cliff Palace enclosure, just where the modern trail heads upward to the canyon rim, there is a smooth trapezoidal platform, as the center of which is
The Sun Temple of Mesa Verde Showing Alignments to the Moon and Sun.

A pecked basin with a diameter of 8 cm and depth of 3 cm. A person standing on the platform over the basin would have seen the winter solstice sun setting over the sun stone and the center of the Sun Temple. It thus appears that the builders of the Sun Temple capitalized on the favorable location of the sun rock, and built the structure in line with the setting winter sun.

It is likely that the D component of the Sun Temple was constructed first, and the less elegant “annex” was added later, perhaps to incorporate the sun stone into the larger structure. A winter solstice ceremony could have been held in the large area near the four story square tower of Cliff Palace. Participants would have watched the sun setting approximately near the center of the Sun Temple. A designated observer or sun priest stationed at the platform could have confirmed that the sun actually did set at its proper place.
Close to summer solstice another astronomical ceremony may have been held in Cliff Palace to watch the setting of the full moon at its most southern position. The full moon is always opposite the sun, so that when the sun is furthest north at summer solstice, the full moon is furthest south. But the moon behaves in a more complex manner than the sun. While the sun always sets at the same place at summer solstice, the full moon at summer solstice oscillates slowly back and forth, reaching its furthest southern extreme, the southern major standstill, every 18.6 years. That kind of oscillation brings the rising moon into the gap between the rock towers of Chimney Rock as seen from the Chimney Rock Pueblo, where in A.D. 1076 and A.D. 1093 construction events coincided with the appearance of the moon between the chimneys. Chimney Rock was abandoned in the first decades of the 12th Century, perhaps 50 years before the construction of Cliff Palace.

During the years approaching the major standstill of the moon, residents of Cliff Palace would have seen the full moonset at summer solstice gradually move southward toward the Sun Temple on the horizon. During two to three years around major standstill, the full moon at summer solstice would set over the Sun Temple as seen from Cliff Palace. At dawn near summer solstice, when life was just stirring in the cliff dwellings, the setting full moon would have provided a spectacular sight on the opposite horizon. One of the best places for staging a public viewing of the moonset is the open area near the four story square tower of Cliff Palace.

A dramatic visual reciprocity could have occurred for several years around the time of the major standstill on the mornings of the full moon near summer solstice. A sun priest may have greeted the rising solstice sun from the center of the Sun Temple. Observers in Cliff Palace could have had a remarkable view of that celebrant on the Sun Temple silhouetted against the setting full moon. If that person were holding a reflecting device such as a mica or pyrite mirror,
Pictograph on the Interior of the four story tower of Cliff Palace. The 75 tick marks which are just to the left of the window that provides a view of the Sun Temple average 18.5 per line, remarkably close to the 18.6 years between major lunar standstills.

the flash of sunrise would signal sunrise just as the moon was setting. A feature of the Sun Temple, which suggests intentionality of design, is that the line tangent to its two interior circular rooms aligns approximately with the major standstill moon set as well as with the four-story square tower of Cliff Palace.

The setting of the major standstill moon would also have been viewed from the window on the third floor of the tower. Next to the window there are four painted lines with tick marks, averaging 18.5 marks per line. If each tick mark represents a year, four standstill cycles could be recorded on the wall of tower during a 75-year period between the major standstills of A.D. 1186 and A.D. 1261. The latter date would have carried this remarkable sun-moon ceremony into the dangerous period at the end of the occupation of the Mesa Verde region. The next major standstill moon would have set over the Sun Temple in A.D. 1279, perhaps at a time when there were no human eyes in Cliff Palace to watch the spectacle. The Great Drought started abruptly in A.D. 1276 and soon thereafter people began leaving the region.
The Sun Temple is a D-shaped bi-wall similar in form though not in orientation to those at Goodman Point and Sand Canyon. The Sun Temple is rotated away from true east-west by 10.7°, and therein lies an interesting story. The perpendicular drawn from its southern wall crosses a basin pecked in bedrock just to the north and extends to another pecked basin in the center of Cedar Tree Tower at a distance of 3.77 km. The line continues another 4.9 km further north to another basin on the summit of Battleship Rock in Soda Canyon. During the late Pueblo II period, the area of Battleship Rock was one of the densest concentrations of people on the Mesa, probably serving as a major ceremonial center for the residents of Mesa Verde. The Battleship Rock community contained some 41 dwellings and 16 kivas as well as a great kiva. The line connecting Sun Temple and Battleship Rock may have been intended as a “line across time” connecting the Sun Temple with the former ceremonial center.

Yellow Jacket Pueblo

The main settlement at Yellow Jacket appears to have been the largest pueblo in the Northern San Juan Region. Set in very fertile landscape (which is now acclaimed as the “pinto bean capital of the world”), the area may have been the “breadbasket” for the ancient Pueblo world. Covering nearly 100 acres, the pueblo contained at least 195 kivas, 19 towers and between 600 and 1,200 rooms, and at its peak it may have had a resident population between 850 and 1,300 people. The village was occupied continuously between A.D. 1060 and 1280. During the final 20 years of occupation, the population dramatically declined. Residents pulled back from the less protected northern boundary and lived primarily along its high spine, protected on three sides by the cliffs of the Yellow Jacket peninsula. The other area with high population density was in the northeast in the area of the Great Tower, where four towers protected the
major spring of the area. The Great Tower Complex contains a bi-wall tower rising above a kiva and a line from the unexcavated Great Kiva to the Great Tower is oriented toward December solstice sunrise.

The Yellow Jacket Pueblo. The two area of high intensity occupation after A.D. 1250 are circled. The Yellow Jacket spring is protected by towers on the east and west. The sightline to December Solstice sunrise from the Great Kiva across the Great Tower is shown. (Artist’s depiction by Jean Kindig.)
The Towers of Hovenweep

The isolated towers of Hovenweep represented a variation on the Yellow Jacket defensive strategy of building towers to protect springs. These buildings were built like castles of the Middle Ages, with few vulnerable windows and accessible doorways, relying on small “portholes” to provide minimal light and ventilation. In spite of the threats they faced the residents of Hovenweep built astronomy into their villages. Worship of the sun and moon may have gained power because they had little else to turn to during these times of drought and danger. During such uncertain and desperate times, they may have turned to the sun for guidance and protection. The lonely towers they built stand guard over scarce water resources. They are beautiful structures, built of carefully shaped and pecked sandstone. One can feel an almost palpable fear in these towers. Perhaps they provided protection for women and children during raids by bands of enemies seeking some of their water during the Great Drought.
Named for its resemblance to the fortresses that dotted the European landscape during the Middle Ages, Hovenweep Castle stands on the rim of a box canyon, above a cool spring. The D-shaped tower to which a number of rooms were attached is a small part of the original building which spilled over the edge down into the canyon. A rectangular room, dubbed the “sun room,” was attached to the southern side of the tower, and it is this room’s ground floor to which astronomers have been drawn.

Hovenweep Castle. Note the defensive positioning of the only doorway. The doorway enters the “sun room.”

From this room, the ancestral Pueblo of Hovenweep Castle could mark June solstice. At the summer solstice sunset, a ray of light streams through a porthole in the sun room, shining on the lintel of the doorway into an eastern room. In all of these cases, the play of light along the wall is noticeable well before the actual date of the solstice or equinox, allowing ancestral Pueblo sun priests sufficient time to plan the appropriate ceremonies. In early April, when the sunray is first visible inside the room, the ancestral Pueblo would have been preparing for the year’s first planting. The long, north wall of the room, along which the light beam travels as the solstice approaches, could well have been scored with vertical marks indicating the days before solstice festivals.
Near Holly House, located in one of the smaller canyons at Hovenweep, two large boulders stand near the canyon wall. The two, with an overhang on one creating a roof, form a tunnel that opens to the east. A third boulder blocks most of the tunnel’s western egress. The ancestral Pueblo carved two large spirals and a sun symbol into the side of the southern rock. Near the summer solstice the rising sun throws two narrow horizontal spears of light onto the spirals and the sun symbol. As the sun rises these spears stretch out toward each other from these carvings, meeting at the center of the blank wall between them. As was the case at Fajada Butte, the ancestral Pueblo did not move the huge boulders into place to achieve the required play of light along the carvings. Rather, someone noticed the unique patterns formed by the rising sun at summer solstice and pecked the designs accordingly. The solar sites at Hovenweep, like those at Chaco Canyon, testify to the skill and ingenuity of the ancestral Pueblo in utilizing natural phenomena at Holly House.

**Castle Rock, Sand Canyon, and Goodman Point Pueblos**

These three Pueblo villages lie some fifteen miles to the east of Hovenweep and display further strategies for coping with the unrest and violence that was sweeping the area at the end of the Pueblo III period. All three had been the targets of attacks, and all were abandoned between A.D. 1080 and 1085. Castle Rock had been built soon after A.D. 1256 around a small butte. Approximately 15 households may have hoped that the butte would have provided protection. The village contained some 37 rooms, 16 kivas, and 9 towers. The last tree ring date is A.D. 1274, and it was destroyed in an attack sometime between A.D. 1280 and 1285. At least 41 of its inhabitants died in the attack. Human remains were found lying on floors, in collapsed roofs, and on top of the butte.
Sand Canyon Pueblo. Note the Great Kiva near the center and the D-shaped bi-wall above it. (Reconstruction by Dennis Holoway.)

Both the villages of Sand Canyon and Goodman Point were built around a spring and surrounded on three sides by a defensive wall. Sand Canyon contained 90 kivas and 14 towers and was occupied between A.D. 1250 and 1280 with a population of 400-600. Judging from healed bone fractures of some of its inhabitants, Sand Canyon had survived several attacks before it was finally abandoned sometime after A.D. 1277. During the last few years of occupation, refuse was deposited on the floor of the Great Kiva and the D-shaped bi-wall was converted into domestic use, indicating they were indeed desperate times accompanied by a loss of interest in traditional ritual activities. Before the final attack, the majority of the residents had emigrated elsewhere, leaving a few to defend the village and the spring. All those who remained apparently died in the final attack, many suffering violent deaths.
Sand Canyon Pueblo. The orientations of the D-shaped bi-wall and Great Kiva are shown. The dashed arrow is to June Solstice Sunrise (Kuckelman 2010).

Goodman Point was larger than Sand Canyon with 114 kivas and a resident population of 570 to 800. It was built in A.D. 1260 and abandoned less than 20 years later. Similar to Sand Canyon, it was enclosed by a massive masonry wall, which was at least one story high. The tallest structure in the village was a D-shaped bi-wall similar to that at Sand Canyon. Similar to Castle Rock and Sand Canyon, there is evidence of violence near the time of abandonment.

What is extraordinary about the Sand Canyon and Goodman Point communities is the attention they paid to the positioning and orientation of their ceremonial buildings during these stressful decades. The orientations of the D-shaped structures and the great kivas at Sand Canyon and Goodman Point were part of a tradition going back at least four centuries and perhaps even further to Basketmaker III. Table A compares orientations of various structures of the Ancestral Pueblos.
Goodman Point Pueblo. The orientations of the Great Kiva and D-shaped structures are shown (Kuckelman et al. 2009).

In addition to abiding with the tradition of orientation to the SSE, the D-shaped bi-walls of Sand Canyon and Goodman Point may also have been intentionally aligned to the June Solstice sunrise. During June of 1993, I led a week-long program investigating the
archaeoastronomy of the San Juan basin. One of our projects was to observe June solstice sunrise within the structures of Sand Canyon, which at that time had not yet been backfilled. We had participants stationed along the wall of the D-shaped building who observed that on the morning of June solstice the sun rose approximately along its straight wall. Great kivas, each aligned approximately to the cardinal directions, were constructed at Goodman Point and at Sand Canyon. In 1986, we measured the orientations of the four roof supports of the Great Kiva at Goodman Point and found an average orientation of 2.5° east of north. Measurements of the map of Sand Canyon give a similar orientation of its Great Kiva: 2.1° east of north.

McPhee Pueblo (right) and Earliest Construction Phase of Pueblo Bonito (left).
These remote villages in the Northern San Juan basin were connecting with ancestors and events of the past that occurred in the Pueblo world centuries earlier. Whatever the meaning of the orientation of the kivas and bi-walls, establishing the direction of true north or an offset to SSE was no easy task. The skies lacked a star that was close to the north celestial pole at that time, and the builders of these structures, with neither magnetic compass nor surveying equipment, had to resort to ingenious methods using the stars and the sun.

The recurrent themes of these Pueblo III settlements (Mesa Verde, Yellow Jacket, Hovenweep, Sand Canyon, and Goodman Point) appear to be concerns for defense, protection of water sources, and the skies. It is not surprising that water and defense were considered to be vital. It is a fascinating insight into the essentials of these communities that almost up to the very end of their days in the Four Corners people must have looked to the sun and moon for guidance and relief.

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