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ABSTRACT

The structure at Mesa Verde National Park known historically as Mummy Lake and more recently as Far View Reservoir is not part of a water collection, impoundment, or redistribution system. We offer an alternative explanation for the function of Mummy Lake. We suggest that it is an unroofed ceremonial structure, and that it serves as an essential component of a Chacoan ritual landscape. A wide constructed avenue articulates Mummy Lake with Far View House and Pipe Shrine House. The avenue continues southward for approximately 6 km where it apparently divides connecting with Spruce Tree House and Sun Temple/Cliff Palace. The avenue has previously been interpreted as an irrigation ditch fed by water impounded at Mummy Lake; however, it conforms in every respect to alignments described as Chacoan roads. Tree-ring dates indicate that the construction of Spruce Tree House and Cliff Palace began about A.D. 1225, roughly coincident with the abandonment of the Far View community. This pattern of periodically relocating the focus of an Anasazi community by retiring existing ritual structures and linking them to newly constructed facilities by means of broad avenues was first documented by Fowler and Stein (1992) in Manuelito Canyon, New Mexico. Periods of intense drought appear to have contributed to the relocation of prehistoric Native Americans from the Far View group to Cliff Palace/Spruce Tree House in the mid-13th century and eventually to the abandonment of all Anasazi communities in southwestern Colorado in the late-13th century.

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1. Introduction

This paper is divided into three parts. In the first part we introduce the structures that make up the Far View group (including Mummy Lake), document the time period during which some of the structures were constructed and abandoned, review the results of previous studies of Mummy Lake, and state the objectives of our study. The second part of the paper presents our hydrologic analysis of the hypothetical Mummy Lake water collection, impoundment, and redistribution system. The third part of the paper presents an alternative interpretation of Mummy Lake's function, i.e., we hypothesize that it was an essential part of a Chacoan ritual landscape that included the Far View group, Cliff Palace/Spruce Tree House and Sun Temple, which were connected by constructed avenues (Chacoan roads).

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1.1. Description and dating of the Far View group

The Far View group of archaeological structures is located on the northern part of Chapin Mesa, Mesa Verde National Park (Fig. 1). Prominent buildings in the group include Far View House, Pipe Shrine House, Coyote Village, Far View Tower, Megalithic House, and Mummy Lake (Fig. 2). An interesting structure in the Far View group that remains unexcavated is a large circular pit (great kiva?) adjacent to Far View House (dotted circle in Fig. 2). Supplementary Fig. 1 is a picture of Pipe Shrine House and Far View House showing the relationship of the two buildings, which are located on a common elevated platform.

The great majority of terminal ring dates from the Far View group are "vv" dates, which implies that we cannot place the terminal ring date within a few years of the death of the tree (its cutting date). However, the distribution of terminal ring dates (Fig. 3) remain useful in defining the overall occupation of Far View group (Robinson and Harrill, 1974). A number of studies that employed different estimation methods (e.g., Graves, 1991; Nash,

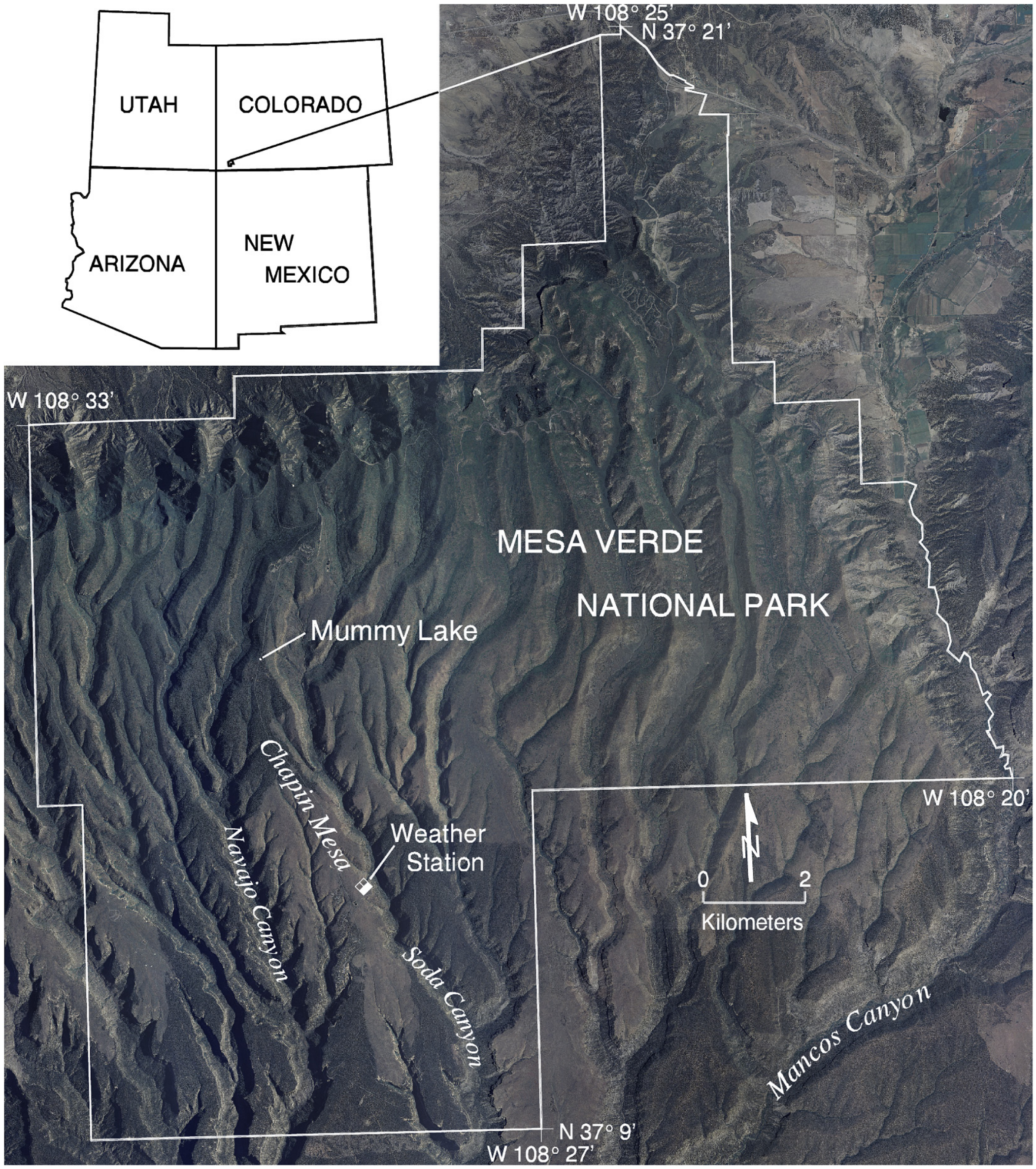

Fig. 1. Location map of Mesa Verde National Park and Mummy Lake study area.

1997) have shown that the terminal ring date of a "vv" sample is often only a few decades older than the tree's death date. Thus, the distribution of terminal dates from Far View House (Fig. 3) suggests that the Far View site was intermittently occupied between A.D. <875 and A.D. 1250. Cutting and "v" dates ("v" dates are only a few years older than cutting dates) from Far View House, although few in number, support this inference (Fig. 3). The few dates that occur prior to A.D. 800 likely indicate the use of dead wood either for new construction or structural repair.

Note the paucity of cutting dates centered on A.D. 1150. This suggests that the pace of construction either slowed greatly or that it was suspended altogether during the middle-12th century megadrought (A.D. 1130–1180) after which construction resumed. Fewkes (1917), when excavating Far View House, found a layer of windblown sand in some of its rooms and noted that "Evidently some of the rooms had been deserted and the sand accumulated to a depth of 2 or 3 feet, after which they (*the rooms*) were reoccupied and foundations laid on the sand, …" Although Fewkes (1917) was unable to date the hiatus in occupation, it suggests that prehistoric Native Americans may have abandoned Far View House during the middle-12th century megadrought, only to return after the climate ameliorated. Alternatively, this fill may be architecture. For example, Morris (1928) observed that ground-level rooms at Aztec West were filled with "relatively clean earth….packed to unbelievable hardness", which Brown et al. (2008) suggested was done to prevent the collapse of standing walls, a cultural, not a natural process.

1.2. Description and dating of Mummy Lake

The focus of this study is an oval masonry-lined structure known historically as Mummy Lake. This structure is 27.5 m in diameter and was originally about 6.65 m deep. The structure is located on the upper part of Chapin Mesa, Mesa Verde National Park, in semi-arid southwestern Colorado (Fig. 4). The Upper Cretaceous Cliff House Sandstone underlies the mesa top, and dips at a low angle toward the south (Condon, 1991). Mummy Lake lies on a ridge line that decreases in elevation from north to south. The stone masonry of Mummy Lake extends a few meters above grade where it serves as the inner wall of an earth filled platform. This

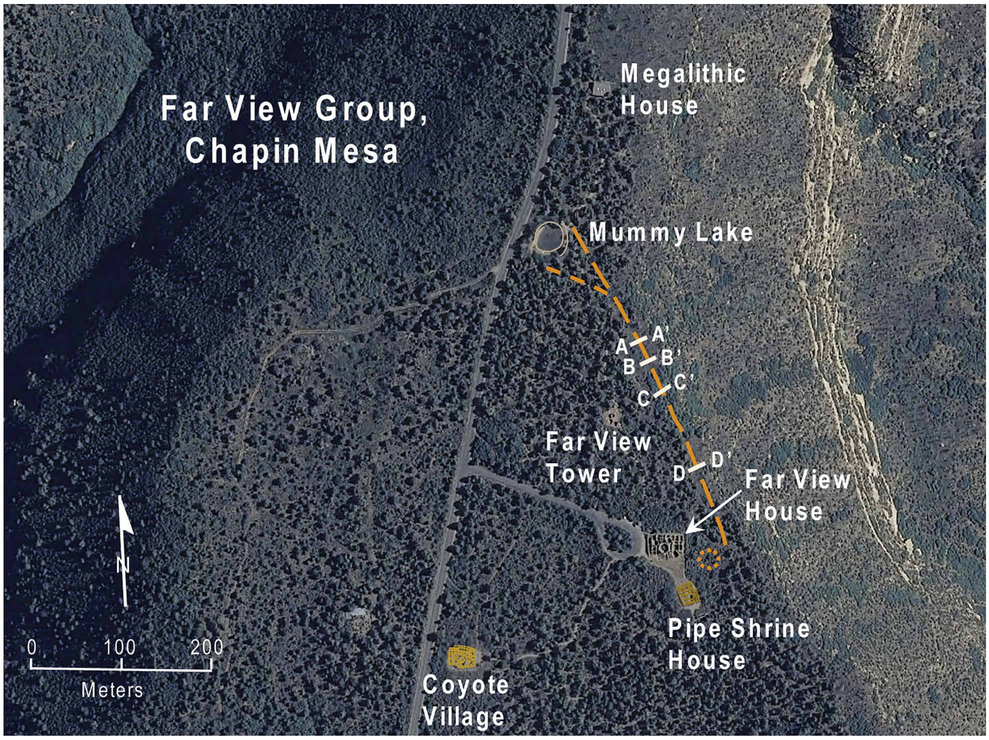

Fig. 2. Location map of Far View group, showing ceremonial road (middle ditch) running from Mummy Lake to east of unexcavated great kiva near Far View House. Lines A–A′, B–B′, C–C′, and D–D' indicate locations of cross sections depicted in Fig. 10. National Park Service image mosaic for Mesa Verde National Park.

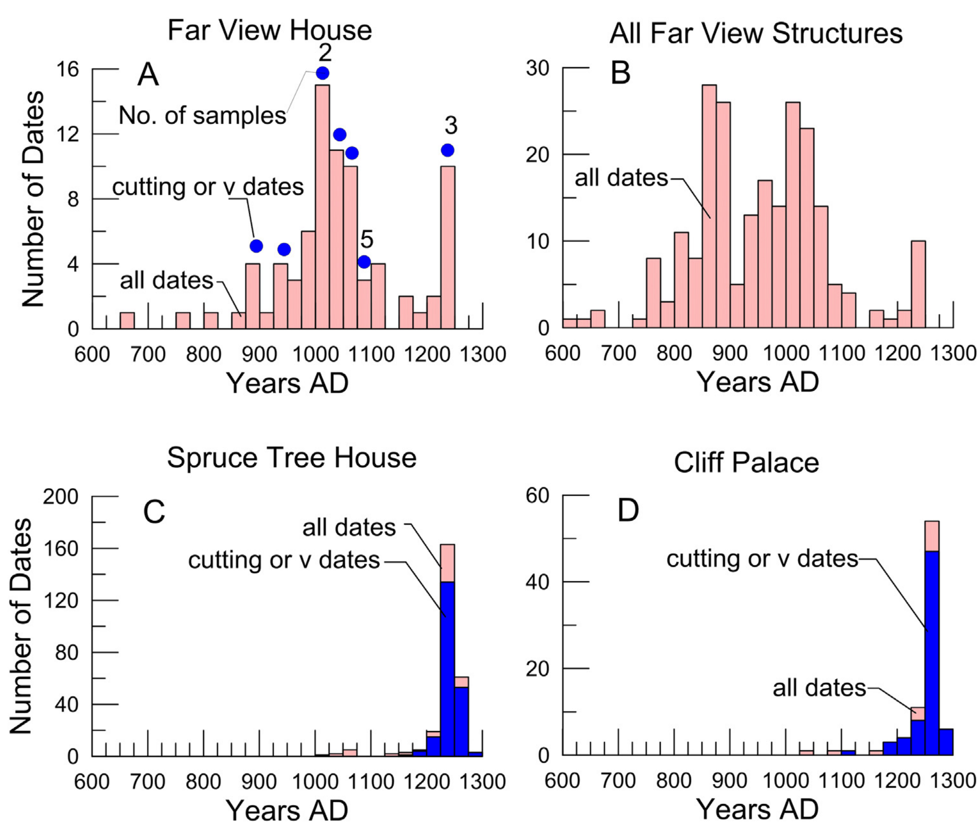

Fig. 3. Tree-ring terminal ring dates for A. Far View House, and B. All Far View structures, C. Spruce Tree House, and D. Cliff Palace. Dots with numbers indicate the number of cutting or “v” dates for that bin.

Fig. 4. Picture of Mummy Lake looking south. Processional entrance is shown on the right side of the photo. Steps on the south side of the lake are hidden by the left most green shrub. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

platform ranges from 4 to 5 m in width and forms the south and east margin of the oval structure. Mummy Lake was and still is the first of the massive surface ruins encountered when one visits Mesa Verde and the exaggerated mass of the earthen platform and masonry retaining wall contributes to its landmark status. Originally interpreted as an irrigation reservoir (Fewkes, 1917), Mummy Lake is central to the argument that the pre-Columbian occupants of Mesa Verde practiced large-scale water management (Rohn, 1963).

Fewkes' (1917) description of Mummy Lake included the observation that the surface between the inner and outer walls was buried by a ridge of earth that he interpreted as accumulated wind-blown sediment. The 1969 excavation and stabilization at Mummy Lake performed by Breternitz (1999) demonstrated that the fill was architectural and intended to create a level elevated surface 4–5 m wide along the south and east sides of the structure (Fig. 5). This exaggerated rim created the appearance of a basin (Fewkes, 1917, Plate 7, Fig. 1), reinforcing the interpretation of this structure as a water storage feature. Access to the interior of the Mummy Lake is facilitated by a stairway built into the masonry wall on the south side (Supplementary Fig. 2), and a low ramp entering the southwest quadrant of the structure. This ramp passes through the platform and abuts the west interior wall as it spirals into the structure (Fig. 6). Prior to our study this ramp was considered part of a water intake system (Breternitz, 1999; Fewkes, 1917). There may have been another entrance on the northern side of Mummy Lake (the Cowboy Ditch) although this feature has been previously attributed to cattlemen breaking through the north bank of Mummy Lake to allow for stock watering (Breternitz, 1999; Fewkes, 1917).

Mummy Lake appears to have been constructed in two phases (Breternitz, 1999) (Fig. 7). In phase 1, the so-called Early Intake Ditch was constructed. In addition two walls, Wall 1 followed by Wall 2, were constructed on the southeast side of the depression. Fill from the depression was placed between the two walls. In phase 2, Wall 3 was constructed inboard of Wall 1, and Wall 1 was then covered with fill. Wall 3, which contains a stone stairway on its southern end, lines the entire depression and the Late Intake Ditch.

Ceramics included within fill material making up the two phases of construction (Breternitz, 1999) give some idea as to the age of Mummy Lake. Ceramic age ranges were taken from Ortman et al. (2005). Cortez Black on White (A.D. 920–1060) was found in the Early Intake Ditch and under walls 2 and 3. Mancos Black on White (A.D. 920–1180) was found in the Early Intake Ditch, under wall 3 and in wall 1. McElmo Black on White (A.D. 1060–1260) and Mesa Verde Corrugated (A.D. 1100–1280) were found in the Late Intake Ditch and Mesa Verde Black on White (A.D. 1180–1280) was found in the wall that blocks the Late Intake Ditch. These data suggest that the first phase of Mummy Lake construction probably occurred during the Pueblo II (PII) period (A.D. 900–1150) and the second phase of construction probably occurred during the Pueblo III (PIII) period (A.D. 1150–1300). Thus, Mummy Lake appears to have been in use during the same time interval as the tree-ring dated structures in the Far View group (Fig. 3).

1.3. Previous studies and interpretations

Different workers have held different ideas regarding whether Mummy Lake was a water-storage feature or whether it was ceremonial in nature (e.g., Chapin, 1892; Fewkes, 1917; Rohn, 1963, 1977; Smith, 1979; Stewart, 1940). Most studies have argued that Mummy Lake was a domestic water-storage feature (although an unreliable one) including the recent studies of Breternitz (1999) and Wright Paleohydrological Institute (WPI) (2000). Fewkes (1917) considered Mummy Lake to be a reservoir but noted "There is no reason for calling this prehistoric reservoir a lake, for it is not a lake and no mummies have ever been found in or near it." In response to the studies of Breternitz (1999) and the WPI (2000), the National Park Service renamed Mummy Lake as Far View Reservoir (Wright, 2006).

Fig. 5. Walled flat surface on east side of Mummy Lake. Wall No. 1 (Fig. 7) is buried under this surface. Wall No. 2 is the outer wall and Wall No. 3 is the inner wall (Fig. 7).

Fig. 6. West side of Mummy Lake. The inclined walled structure was previously interpreted to be an intake ditch. We consider this feature to be a processional ramp.

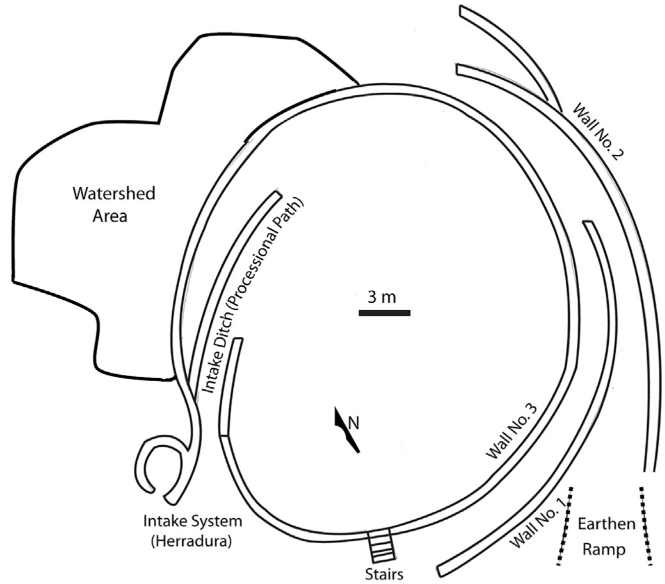

Fig. 7. Construction phases of Mummy Lake. The horseshoe-shaped feature in the lower left of this illustration was originally interpreted to be part of a surface-water intake system that contained a sediment settling basin. We suggest that this feature is a herradura, commonly associated with ceremonial roads in the American Southwest.

Stewart (1940) also claimed to have located and mapped an irrigation canal, which he called Indian Ditch that emanated from Mummy Lake and ran south past the east side of Far View House to the vicinity of Spruce Tree House. He believed that this flood-water ditch supplied water to maize fields along the mesa top and that Mummy Lake was the beginning of the water distribution system. We will refer to the upper part of this ditch that runs from Mummy Lake to Pipe Shrine House as the middle ditch and the lower part of this ditch that runs from Pipe Shrine House to the vicinity of Spruce Tree House, as the lower ditch. Fewkes (1917) also mentioned the lower ditch and suggested that it was an “old Indian path of great antiquity that connected the Far View group with Spruce Tree House and Cliff Palace”.

Rohn (1963) proposed a water collection and distribution system (Fig. 8) consisting of a 10 hectare (ha) collection area on the relatively flat, upper part of the mesa, a gathering basin at the head of a draw, and a compacted footpath that served as a feeder ditch to convey water another 1000 m along the ridge crest to Mummy Lake. We will refer to this hypothetical ditch as the upper ditch. Rohn (1977) suggested that when the Far View populace moved to Cliff Canyon at the beginning of the Pueblo III period, they took their artificial water supply with them by creating the lower ditch. Smith (1979) argued that the lower ditch could not have been a canal given its dimensions relative to the limited precipitation that falls on Chapin Mesa. He believed that the lower ditch was an old stock or horse trail cleared during the historic period.

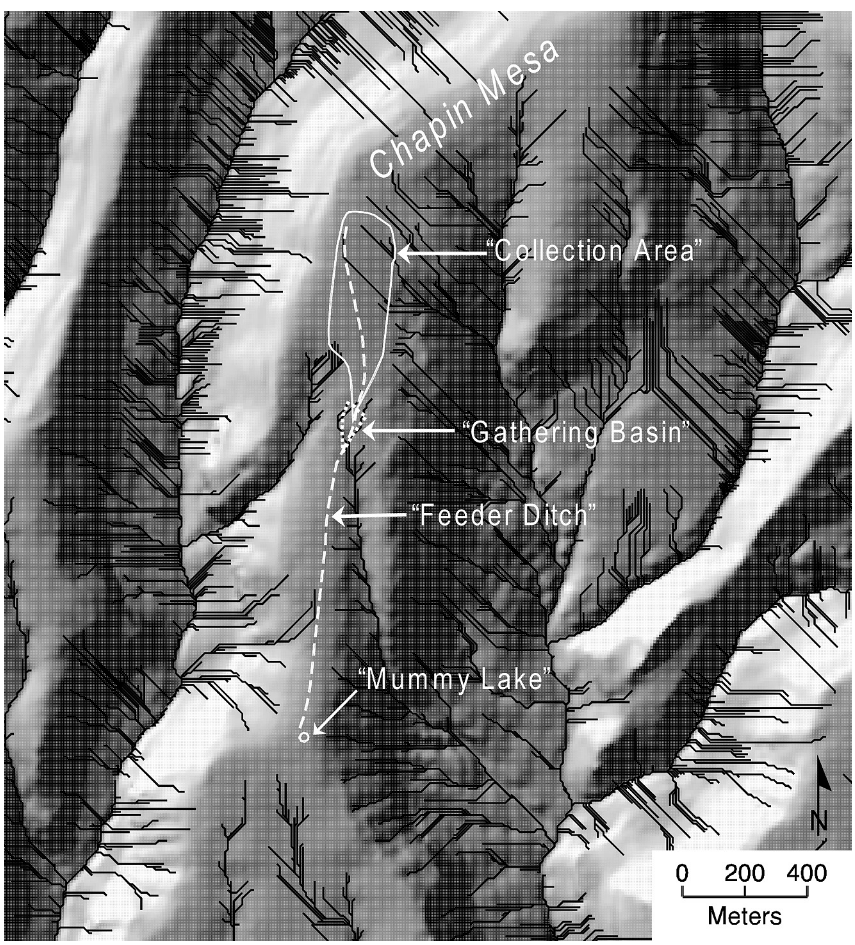

Fig. 8. Relief map showing the location of Rohn’s (1963) gathering basin and collection area as well as the hypothetical upper (feeder) ditch that supposedly carried water to Mummy Lake. Note the ridge crest location of the ditch. Black lines are drainage pathways identified from a 10-m seamless NED DEM.

Leeper (1986) applied a watershed and channel routing model to the Mummy Lake water collection system and concluded that the "collection system would have been hydrologically and hydraulically unable to deliver water for irrigation or domestic purposes." More recently, the WPI (2000) applied hydrological and engineering investigations to evaluate Rohn's (1963) hypothesized water collection and distribution system. Their evaluation of water collection and storage potential in the structure was based on results of their investigations as well as findings from Breternitz's 1969 excavation of Mummy Lake (reported in Breternitz, 1999). Their data did not include a more recently available 10-m seamless Digital Elevation Model (DEM) (Gesch, 2007), and they did not address the effects of suspended sediment transport and deposition on the diversion and conveyance of water to Mummy Lake.

WPI (2000) concluded that perched groundwater was not a source of water for Mummy Lake, but that surface water was supplied to the structure by snowmelt and diversion of runoff. WPI (2000) computed potential runoff and delivery of water to Mummy Lake using the following assumptions: (1) the assumed area of compacted soil was 20% of Rohn's (1963) collection area; i.e., the watershed contained a 2-ha area of relatively impervious, bare soil compacted by foot traffic, (2) the infiltration rate averaged 5.3 cm/h (hr), and (3) when the rainfall rate exceeded 2.8 cm/h, infiltration could not keep up with the water flux and surface-water runoff occurred.

The hypothetical delivery ditch was assumed to have a concave-up shape, about 1-m wide and 0.12-m deep in the center (WPI, 2000, p. 20). The slope used in the hydraulic analyses was −0.048. It was assumed that surface roughness was relatively high in the un-vegetated, compacted footpath, such that Manning's *n* (Manning, 1891) was set to 0.040. For comparison, Chow (1959) gives a range of Manning's *n* values from 0.018 to 0.025 for a clean, weathered earthen surface with no vegetation. Manning's *n* is a coefficient which represents the surface roughness applied to flow in a channel.

As a result of their calculations, WPI (2000) concluded that Mummy Lake was used for the occasional storage of domestic water that was supplied by snow melt and surface-water runoff, and that surface-water runoff was conveyed to Mummy Lake by the hypothetical foot-packed trail.

In summary, archaeologists and engineers disagree on the ability of Mummy Lake to collect and redistribute surface water and they also disagree on the function of the ditches that connect Mummy Lake with the Far View group and Cliff Palace/Spruce Tree House.

1.4. Objectives

This study has two objectives: (1) to apply hydrologic and sediment transport models to the area surrounding Mummy Lake to determine its ability to gather, store, and distribute water, and (2) to assess the possibility that Mummy Lake was actually an unroofed ceremonial structure embedded in a ritual landscape wherein the middle and lower ditches functioned as constructed ceremonial avenues connecting Mummy Lake to the Far View group and the Far View group to Spruce Tree House/Cliff Palace and Sun Temple.

2. Hydrologic evaluation of Mummy Lake

2.1. Methods

2.1.1. Topographic data and imagery

The geomorphic setting of the Far View group on Chapin Mesa was determined using high-resolution imagery, a 10-m digital elevation model (DEM), and data from a high-precision Global Positioning System (GPS) survey. These data enabled a detailed analysis of spatial relationships between constructed and geomorphic features and also allowed us to quantify potential direct precipitation, runoff, and conveyance of water to Mummy Lake.

Imagery obtained from the National Park Service (National Park Service, 2009) shows the spatial setting of Mummy Lake within the Far View group on Chapin Mesa (Fig. 2). The image mosaic was derived from 1-m natural color imagery produced by the U.S. Department of Agriculture's National Agricultural Imagery Program (U.S. Department of Agriculture, 2009).

A surface hydrologic analysis was performed using a 1/3 arc second (∼10 m) seamless DEM obtained from the U.S. Geological Survey's National Elevation Dataset (NED) (Gesch, 2007). The NED DEM is a $1^\circ \times 1^\circ$ tile in which the source 7.5-min (1:24,000-scale) DEMs have been processed to remove production artifacts (Oimoen, 2000) and edge-matched to produce a seamless elevation model suitable for hydrologic analysis (Gesch, 2007). This process provides local slope continuity across "seams", which is particularly important for hydrologic analysis in areas like Chapin Mesa, which extends across four 7.5-min maps.

Prior to performing the hydrologic analysis, the DEM projection was converted from Geographic, decimal degrees, referenced to the North American Datum of 1983 (NAD 83) and with elevation referenced to the North American Vertical Datum of 1988 (NAVD 88), to UTM, Zone 12, in meters. In the process of changing the projection, the DEM was resampled using cubic convolution to maintain a smooth, continuous surface (Environmental Systems Research Institute (ESRI), 2006). Cell size of the re-projected DEM is 9.234 m × 9.234 m, with a cell area of 85.27 m^2.

Drainage pathways from the top of Chapin Mesa to side canyons were identified from the DEM using Arc Grid (ESRI, 2006) flow direction and accumulation functions. Streamlines (flow pathways) were identified by specifying a relatively low flow accumulation threshold of 25 cells, with a total area of 2132 m^2. The resulting streamlines (black lines in Fig. 8) are denser than those on the 7.5-min maps of the area, but they serve to highlight the drainage direction on the mesa top away from the narrow ridge crest and toward the side canyons.

Potential water flow into Mummy Lake was determined from data collected during a high-precision GPS survey of Mummy Lake and surrounding terrain conducted in June 2010. A grid surface created from this dataset was used to obtain a high-resolution elevation profile approaching the structure along the upper ditch path. In addition, this surface was used to compute the area of natural drainage into Mummy Lake (Fig. 7). This survey included other archeological features within the Far View group, including the middle ditch connecting Mummy Lake to Pipe Shrine House (Supplementary Fig. 3) and the measurement of four east-west cross sections that transected the ditch.

GPS data for the project was collected with two Trimble Pathfinder Pro GPS units.[1] One unit was set up at a fixed location as a base station to collect data at a location with established coordinates (a benchmark). The second unit was used as a rover to collect location data for elevation-surface creation and georeferencing of major archaeological structures. Trimble Pathfinder Office (Version 2.7) with the centimeter post-processing option was used to post process the GPS data collected in the field to centimeter accuracies using carrier phase data. This coordinate information was used to post process all of the rover data using data collected with the base station.

[1] Use of trade, product, or company name within this paper does not constitute an endorsement by the US Government.

Due to the dense tree cover throughout most of the project area, we were unable to maintain consistent lock on enough satellites to achieve "fixed" solutions with the majority of the data. As a result, the estimated root-mean-square error (RMSE) of the vertical positions of the data ranged from 0.03 to 0.25 m, (relative to the base station) with the majority of the data having an estimated RMSE of ≤0.15 m.

To create the elevation model, both spot elevations (point data) and break-line data were collected. Collection areas were restricted to locations with sparse tree canopy that would give the GPS receiver a clear enough view of the sky to allow GPS data collection from a minimum of four satellites. Due to the dense tree canopy, same areas were not accessible; however, we were able to capture sufficient elevation data to create a generalized representative surface of the archaeological site.

To map the lower ditch that leads from near Pipe Shrine House to the general area of Spruce Tree House, we used a handheld Garmin GPSmap 60CSx unit, which was usually accurate to within three horizontal meters.

2.1.2. Climate data

Ceramic and tree-ring evidence (Sections 1.1 and 1.2) indicate the Far View group was in use from sometime prior to A.D. 875 to A.D. 1250. In order to determine the amount of water stored in Mummy Lake, we needed to perform a water balance and, therefore, needed data for precipitation (snow and rain), bare-soil evaporation, and evaporation/sublimation of the snowpack.

Tree-ring reconstructions of water-year (WY) (October 1 through September 30) precipitation from Mesa Verde indicate an average rate of 45.6 cm/yr for the period A.D. 875–A.D. 1250 (Benson et al., 2013) (Fig. 9) whereas measured precipitation rates at Mesa Verde for the period 1896–2010 yield an average rate of 45.5 cm/yr. Given that the Mesa Verde weather station's precipitation record was increasingly compromised by missing daily values prior to 1949, estimation of precipitation rates from 1896 to 1948 was done using PRISM data from the grid point nearest the Mesa Verde weather station (Supplementary Appendix 2 in Benson et al., 2013). Thus the historical precipitation rates are considered representative of precipitation rates during the occupation of the Far View group.

Daily and hourly surface observations from the COOP weather station at Mesa Verde National Park (National Climatic Data Center, 2011) were used to support the rainfall frequency values used by WPI (2000) in their runoff calculations. Monthly climate data from the conventional weather station located on Chapin Mesa about 5 km south of and 193 m in elevation below Mummy Lake were obtained from the Western Regional Climate Center (2011). These records include total monthly precipitation (January 1922 through March 2011) and total monthly snowfall (winter of 1922–1923 through winter of 2010–2011) data.

Pan evaporation data are not available from the Mesa Verde weather station. In order to estimate evaporation rates on Chapin Mesa, we obtained pan evaporation data from three other weather stations (Table 1) within the Four Corners area that were within about 300 m elevation of the Mesa Verde weather station. For all months other than December, January, and February, we used average period-of record monthly pan-evaporation rates from the three sites and multiplied the average pan evaporation rate by 0.8 to estimate monthly free-surface evaporation rates (Western Regional Climate Center, 2011). The estimated monthly free-surface evaporation rates range from 5.6 cm (0.22 cm/day) in March to 16.5 cm (0.55 cm/day), in June and July with an average of 10.9 cm (0.36 cm/day) from March through November. The summer rates measured at these three sites are within the range reported by others for the American Southwest, from 0.5 to 0.8 cm/day (Abdul-Jabbar et al., 1983).

Loss of snowpack to evaporation and sublimation was estimated for December, January and February using an average 1.2 cm/month value (0.04 cm/day), reported by Molotch et al. (2007) from measurements at a site in north-central Colorado. Elevation of their study site (3050 m) is about 690 m higher than Mummy Lake, and the average value from Molotch et al. (2007) is somewhat higher than that (0.02 cm/day) adopted by Benson (2011). However, the snowpack evaporation rate used here represents only about 11% of the estimated average free-surface evaporation rate (0.36 cm/day), and water loss to winter evaporation/sublimation is small compared to in the spring and summer bare-soil evaporation losses.

2.1.3. Calculations of sediment transport along the feeder ditch

We used the variable surface slopes obtained from the DEM and assumed that the surface roughness of the compacted footpath was the result of grain roughness alone. This simulates a much smoother surface than the relatively high value of Manning's n used by WPI (2000). Grain roughness was computed following the method of Wiberg and Rubin (1989), modified using the expression of Gelfenbaum and Smith (1986) to account for momentum loss due to high concentrations of suspended sand. WPI (2000) computed discharge in the ditch assuming a flow depth of

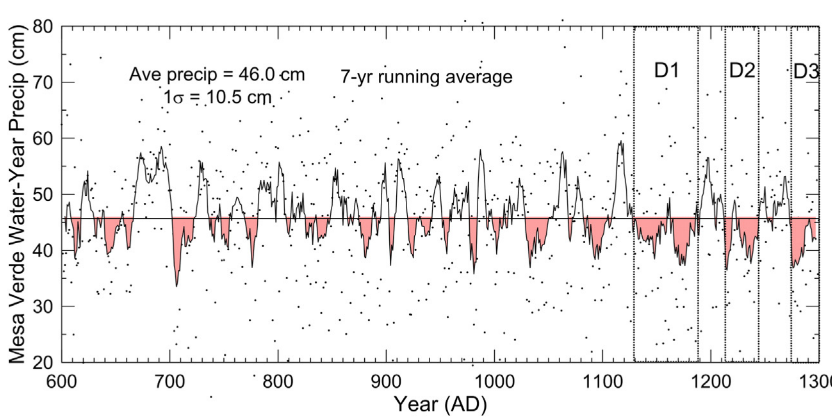

Fig. 9. Tree-ring reconstruction of Mesa Verde water-year precipitation between A.D. 600 and A.D. 1300. This figure adapted from Benson et al. (2013) shows the prevalence of three intense drought between A.D. 1130 and A.D. 1300. We suggest that D1 (the middle-12th century drought) caused the initial abandonment of Native Americans occupying the Far View group. After their return, D2 (the A.D. 1215–A.D. 1245 drought) resulted in the final abandonment of Far View group; and D3 (the late-13th century drought) led to abandonment of the entire region.

Table 1
Weather station locations.

Coop station	Coop ID	Latitude	Longitude	Elevation (m)
Mesa Verde National Park, CO	055531	N 37° 12′	W 108° 29′	2167
Arboles, CO	050307	N 37° 01′	W 107° 25′	1884
Vallecito Dam, CO	058582	N 37° 22′	W 107° 35′	2332
El Vado Dam, NM	292837	N 36° 36′	W 106° 44′	2073

0.12 m. The lower roughness value used in our computation was expected to result in higher calculated discharge; therefore, we iterated on flow depth to find the depth at which discharge was in the range computed in the WPI (2000) study.

Flow characteristics and suspended sediment transport rates were first computed for the low-gradient segment approaching Mummy Lake (slope −0.025), and then for the steeper ditch segment along the narrow ridge crest (slope −0.072). The steeper slope results in higher flow velocities and higher discharges for the same depth. Therefore, we iterated on flow depth to find the depth in the steep segment that resulted in about the same discharge as the lower-gradient segment.

Cross-sectional area as a function of depth was determined for the hypothesized concave-up ditch and an initial estimate of flow discharge was made using the maximum depth (0.12 m) and grain roughness computed using the method of Wiberg and Rubin (1989). Following McLean (1992), we assumed that momentum extracted by the horizontal acceleration of particles near the bed occurred within the bedload layer. In this situation, Wiberg and Rubin (1989) suggest that the apparent roughness is proportional to the thickness of the bedload layer. Assuming a nominal grain diameter of 0.13 mm (fine sand), the roughness height (z_0) computed using the method of Wiberg and Rubin (1989) is 0.014 mm. This value is comparable to roughness computed using the method of Whiting and Dietrich (1990) from the coarse fraction of a heterogeneous bed as $z_0 = 0.1D_{84}$, where D_{84} is the grain diameter for which 84% of the bed is finer than.

The initial estimate of flow velocity in the low-gradient segment of the ditch was made by first computing the shear velocity, u_* (m^3/s), equal to$(\tau_b/\rho_f)^{1/2}$, where τ_b is the boundary shear stress, equal to$\rho_f g h_{avg} S$, ρ_f is the bulk fluid density, g is acceleration due to gravity (9.81 m/s^2), h_{avg} is the average depth (m), and S is the surface slope. For the initial estimate, the bulk fluid density is assumed to be the density of water. Assuming steady, horizontally uniform, and fully turbulent flow, the vertically averaged flow velocity, U, can be estimated from h_{avg}, S, and estimated roughness using a quasi-logarithmic velocity profile,

$$U = \frac{u_*}{k}\left(\ln\left(\frac{h_{avg}}{z_0}\right) - 0.74\right), \quad (1)$$

where k is von Karman's constant, 0.408. This equation results from matching a parabolic profile in the outer part of the flow (away from the bed) to a logarithmic profile near the bed at two tenths of the depth (Wiberg and Smith, 1991). Discharge, Q (m^3/s), was determined from the relation,

$$Q = UA, \quad (2)$$

where A is the cross-sectional area of the water in the feeder ditch. The result from the initial estimate of depth was a mean flow velocity of 2.27 m/s and discharge of 0.177 m^3/s, compared to a maximum discharge computed by WPI (2000) of 0.079 m^3/s. Flow depth was then reduced until the calculated flow discharge was within the range computed by WPI (2000); i.e., from 0.031 to 0.079 m^3/s. When depth is reduced to 0.08 m, the computed flow discharge is 0.077 m^3/s. Flow parameters for this case (Table 2) were then used to compute suspended sediment transport in the ditch flow.

Concentrations of sediment in suspension were computed using the method of McLean (1992), specifying five sediment sizes to represent the sediment available for suspension (Table 3). When effects of density stratification are negligible, McLean's method includes use of a Rouse-type profile (Rouse, 1937):

$$\frac{c}{c_a} = \left(\frac{z_a(h-z)}{z(h-z_a)}\right)^P, \quad (3)$$

where c is sediment concentration, c_a is the reference concentration, z is vertical distance above the bed, z_a is the distance above the bed where $c = c_a$, $P = w_{si}/ku_*$, and w_{si} is the settling velocity for particles in the ith size range. The reference concentration was calculated following the method of Smith and McLean (1977) using the equation

$$c_a = \frac{\gamma_0 c_b (T_* - 1)}{1 + \gamma_0 (T_* - 1)}, \quad (4)$$

where c_b is the spatially averaged concentration of sediment in the bed available for transport, T_* is the transport stage, τ_b/τ_{cr}, $\gamma_0 = 0.004$ (P.L. Wiberg, reported by McLean, 1992), and τ_{cr} is the critical shear stress for the estimated bed material size, D_{50}.

The vertical distribution of sediment in suspension is affected by the distribution of sediment available for transport (Hunt, 1954; Smith and McLean, 1977). We have no way of knowing the actual size distribution of sediment on the ancient footpath. However, we can make a reasonable estimate by using a size distribution representative of a sandy loam soil (Table 3), with 60% of the available sediment in the very fine to medium sand range (0.06–0.50 mm). As noted by Topping et al. (2007), the fractional area of the bed over which sand is available for transport affects the concentration of sand in suspension. We assumed sand and finer material were available for transport on half the bed (footpath).

Increasing concentrations of sediment in suspension increases ρ_f, thereby increasingτ_b; therefore, the computation of suspended sediment concentration profiles requires iteration, with adjustment of τ_b using the computed value of ρ_f from the previous step. Increasing bulk fluid density also affects the sediment particle settling velocities, thus, settling velocities also were adjusted appropriately for the increase in fluid density using the method of Dietrich (1982).

Flow parameters for the steeper ditch segment (slope −0.072) were computed in a similar manner, beginning with the flow depth (0.08 m) found for the low-gradient segment. Iteration on the flow

Table 2
Computed flow parameters for a concave ditch with center depth 0.12 m and top width 0.91 m.

Slope	h (m)	A (m^2)	b (m)	h_{avg} (m)	τ_b (N/m^2)	u_* (m/s)	U (m/s)	Q (m^3/s)
0.025	0.080	0.044	0.84	0.052	14.2	0.112	1.75	0.077
0.072	0.067	0.034	0.79	0.043	38.5	0.174	2.32	0.079

h is the center (maximum) depth.
A is cross-sectional area.
b is the top width at the given center depth.
h_{avg} is the cross-sectionally averaged depth, $=A/b$.
u_* is the shear velocity.
τ_b is the boundary shear stress.
U is the vertically averaged velocity.
and Q is the flow discharge.

Table 3
Assumed bed material grain-size distribution of suspended sediment.

Grain size (mm)	Fraction of bed	Critical shear velocity $(u_*)_{cr}$	Settling velocity[a] (m/s)
0.016	0.25	0.0073	0.0001
0.05	0.15	0.0087	0.0014
0.07	0.35	0.0096	0.0023
0.13	0.15	0.0102	0.0076
0.26	0.10	0.0132	0.0207

[a] Settling velocities were computed using the method of Dietrich (1982), with bulk fluid density = 1170 kg/m^3.

depth led to a depth that resulted in flow discharge within 5% of that computed for the low-gradient case.

2.2. Results

2.2.1. Location and hydraulic properties of ditches running from Mummy Lake to Far View group and from Far View group to Spruce Tree House/Cliff Palace

The path of the middle ditch that runs from immediately south of Mummy Lake to the east of Pipe Shrine House is shown in Fig. 2, and four cross sections mapped perpendicular to the ditch (Fig. 2) are depicted in Fig. 10. Note that two of the four cross sections would today not hold water as they slope east to the canyon wall that borders the ditch.

The lower ditch begins just south of Pipe Shrine House and trends south following the ridge crest. This excavated feature is several centimeters deep and up to 15 m in width. The ditch can be easily traced for a distance of 6 km where it is obscured by the construction of the Mesa Verde Park Headquarters. A shrine-like structure at the southern end of the lower ditch suggests that the alignment divides to connect with both Spruce Tree House and Cliff Palace (Fig. 11). Note that, for the most part, the lower ditch follows the ridge crest, preventing its gathering of water from sloping areas on either side of the ridge crest.

The gradient along the lower ditch is a consistent 0.029, which is an order of magnitude steeper than the alluvial river valleys irrigated by the Hohokam culture in south-central Arizona (Waters and Ravesloot, 2001).[2] Topographic gradients away from the ridge crest toward side canyons are even steeper. The steep slopes would have required numerous hardened structures to control the flow of water down the mesa top, and no evidence of such structures has been found. Along the lower ditch, high infiltration rates in unsaturated, uncompacted soils (an average of 5.3 cm/h; WPI, 2000) exceed the rainfall intensity of a 10-year, 30-min rainfall event, which is 2.8 cm/h. As a result, direct runoff down the ditch would have been rare.

Both ditches discussed above comprise the “Indian Ditch” mapped by Stewart (1940); however, these ditches could not have functioned as canals or irrigation distribution systems given their topographic location and geometry; i.e., the upper ditch would have spilled water over the canyon edge and the lower ditch would have received water only from rain and snow that fell directly on the ditch, forms of precipitation that would have quickly infiltrated the silty loam lining the ditch.

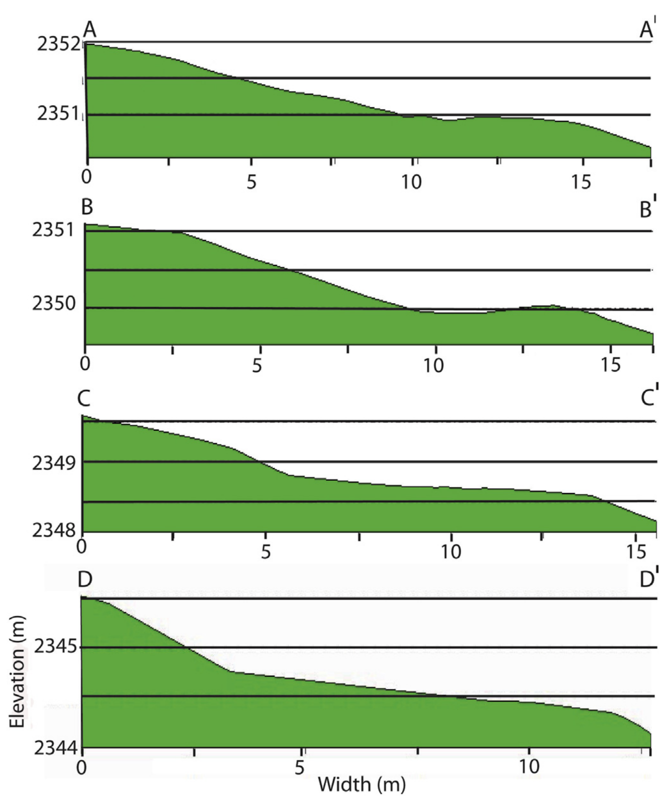

Fig. 10. Middle ditch cross sections whose locations are shown in Fig. 2. Note that water would have run out of the ditch at cross sections C–C′ and D–D′ and would have flowed into the canyon that borders the eastern edge of the Far View group study area.

2.2.2. Mummy Lake water storage

Potential accumulation of water in Mummy Lake from direct precipitation, rainfall and snow, was computed using historical data for a typical WY (1988) and for the wettest year on record (1941). Average WY precipitation is 46.4 cm with a standard deviation of 11.3 cm (1925 through 2010). The reader will note this value is slightly higher than the value calculated for the period 1896 to 2010 that incorporated PRISM data. Monthly precipitation is fairly uniformly distributed through the fall and winter (Fig. 12), declines from April to July, then increases again in July with the onset of the summer monsoon. Fall and winter precipitation (October 1 through March 31) accounts for an average of 53.7% of the total WY precipitation. Average fall/winter precipitation during the period of record is 24.9 cm, including an average annual snowfall of 205 cm (Western Regional Climate Center, 2011).

During WY 1941, precipitation in every month from December through June was well above average (Fig. 12). Total snowfall during the fall and winter of 1940–1941 was 335 cm, 63% more than average. The total water-equivalent depth was 39 cm. The wet winter of 1940–1941 was followed by an exceptionally wet spring, with the total precipitation from April through June reaching 19.5 cm. Thus, data for WY 1941 represents conditions most favorable to storage of snowmelt water in Mummy Lake through the spring and early summer.

Monthly precipitation from WY 1988 represents conditions during a typical year, with total annual precipitation of 50.1 cm and total winter precipitation of 26.3 cm. Total spring precipitation from April 1 through June 30 was 11.2 cm. Spring precipitation received at the Far View site over the period of record actually averages only 7.6 cm.

The land-surface area contributing direct surface runoff to Mummy Lake (Fig. 7), computed using the Arc Grid surface hydrologic analysis functions (ESRI, 2006), is about 986 m^2, which is only 55% larger than the area of Mummy Lake (638 m^2). The limited catchment area is the result of the structure’s proximity to the ridge

[2] The water-surface slopes for the Salt and Santa Cruz Rivers within the area of influence of the Hohokam were obtained from Phillips and Ingersoll (1998).

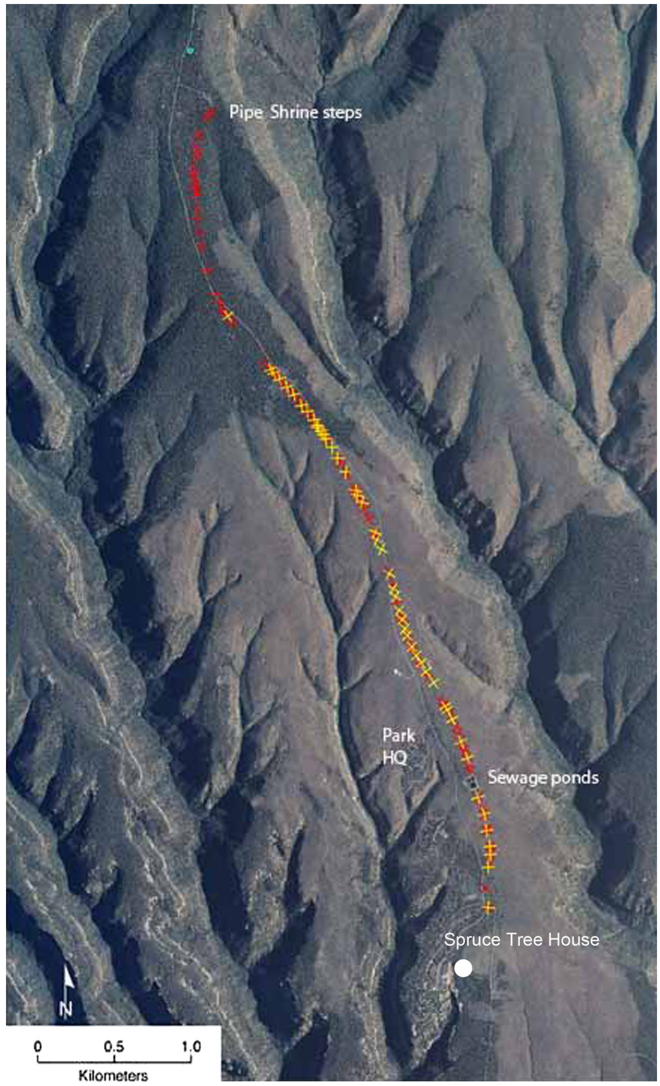

Fig. 11. Relief map (National Park Service imagery, 2009) showing location of the lower ditch that runs from Pipe Shrine House to the vicinity of Spruce Tree House. Sun Temple and Cliff Palace are located near Spruce Tree House. We suggest this ditch is a ceremonial road.

crest; thus, most of the surface slopes away from the ridge crest toward side canyons (Fig. 8). Fewkes (1917) noted the capability of Mummy Lake to retain water, and WPI (2000, p. 46) attributed this to the occurrence of relatively impermeable sandstone bedrock and clay loam that underlies Mummy Lake and the nearby watershed.

The limited catchment area and geometry of Mummy Lake make it possible to examine the water storage potential of this structure,

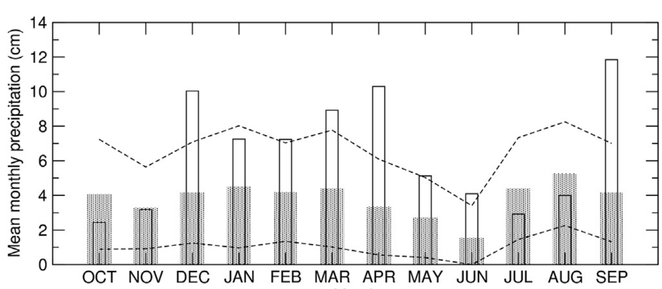

Fig. 12. Mean monthly precipitation (gray boxes) compared to total monthly precipitation in WY 1941 (unfilled rectangles). The dashed lines indicate the range of ±1-sigma values for the period of record.

using monthly precipitation, evaporation, and sublimation data. Cumulative monthly precipitation data, including cold-season snow-water-equivalent data, minus monthly evaporation and sublimation values are shown in Fig. 13 for WY 1941 and 1988. Neglecting water losses due to infiltration over the watershed and Mummy Lake, the water balance indicates that, during a typical year (WY 1988), water remaining in Mummy Lake in March would have evaporated by the end of April.

During the exceptionally wet WY of 1941, water would have accumulated to a depth of 24.6 cm in Mummy Lake by the end of April. However, evaporation and sublimation would have been sufficient to desiccate Mummy Lake by the end of July. Therefore, in all but the most exceptionally wet years, winter and spring precipitation would not have provided sufficient water for domestic use by the Far View community beyond the end of April.

2.2.3. *The effects of sediment transport on the hypothetical feeder ditch*

As mentioned, previously both Rohn (1963) and WPI (2000) envisioned the existence of a feeder ditch that ran from upland farming areas (the hypothetical collection area) to Mummy Lake.

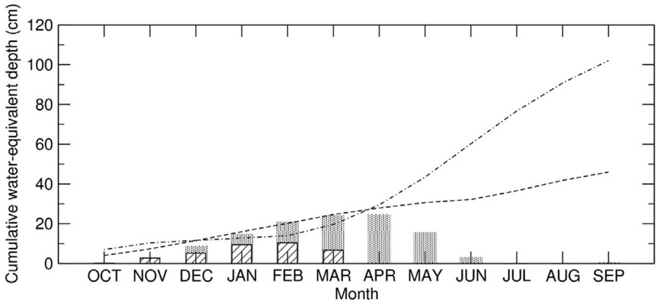

Fig. 13. Accumulated monthly precipitation (depth of rainfall plus water-equivalent depth of snowfall) minus values of mean monthly evaporation and sublimation. The combined evaporation and sublimation potential (dashed line that reaches a value >100 cm by September) is more than twice the cumulative mean-monthly precipitation (dashed line that reaches 45 cm by September) by the end of the water year on September 30th. The gray shaded boxes are monthly net water balances (cumulative precipitation − monthly evaporation/sublimation) in a very wet year (1941), and the hachured boxes are monthly net water balances for an average year (1988).

The existence of this ditch was hypothesized to have resulted from soil compaction caused by human traffic from the fields to the reservoir. Without the existence of this ditch, which lies along a ridge crest, nearly all precipitation upslope of Mummy Lake would have discharged over the cliff that bounds the east side of Chapin Mesa before reaching Mummy Lake. In the following, we examine sediment flux along the ditch from the hypothetical collection area to Mummy Lake using discharge rates consistent with those calculated in WPI (2000).

Elevation from the DEM indicates the upper limit of the hypothetical collection area is located at about 2451 m; average slope through this area is −0.068 (Fig. 14). The decrease in elevation through the collection area along the 650-m ditch to the gathering basin is ∼43 m. Within the gathering basin (Fig. 8) at the southern terminus of the collection area, the slope steepens to −0.127. During high runoff events, this location is the site of naturally converging flow (Fig. 8), which increases flow depth and, as a result, the shear stress on the surface (τ_b).

Increasing the shear stress will cause higher rates of surface erosion at this location relative to the adjacent mesa top and results in the observed increase in slope. Decreasing the shear stress results in the deposition of suspended sediment, and attempts to divert flow to the feeder ditch at this point using a low wall perpendicular to the slope (Rohn, 1963) would have resulted in rapid sedimentation in the ditch. This process would have quickly formed a level surface similar to those observed above numerous check-dams mapped by Rohn (1963), which were considered suitable for tillage. This process would have forced remaining water flow out of the ditch and onto a steep slope, driving the water toward the adjacent canyon. However, for the analysis below, we will ignore this issue and assume that water might have been successfully diverted into the ditch.

The slope along the narrow ridge crest approaching Mummy Lake averages about −0.072 until about 250 m uphill from the structure, where the average slope drops to −0.025 (obtained from the DEM and confirmed by the GPS data-derived grid). Effects of this 65% reduction in the slope on the ditch flow and sediment transport are examined next.

Computed ditch-flow parameters (Table 2) indicate that shear stresses are much higher than the critical values for transport of available sediment. For example, the critical shear stress τ_{cr} for erosion of fine sand (D = 0.13 mm) in clear water is about 0.13 N m^{-2} (Wiberg and Smith, 1987). Computed shear stresses for both slopes (Table 2) are two orders of magnitude greater than critical values for available sediment. The high shear stresses are the result of the steep gradients and the assumed smooth ditch surface.

It is the divergence of the shear stress that can result in erosion (increasing shear stress) or deposition (decreasing shear stress) of sediment. Therefore, on relatively steep slopes covered by loose silt- to sand-size sediment, flow less than 10-cm deep unobstructed by vegetation or other forms of roughness can lead to considerable erosion. On the other hand, suspended sediment will be deposited at sites of reduction in slope. Examples of such a process are provided in a recent study by Slattery et al. (1994).

At the point of transition from the steep-slope to the low-slope ditch segment, the 65% reduction in slope results in a 63% reduction in the boundary shear stress while maintaining about the same discharge. Average water depth would increase from 0.043 to 0.052 m to maintain about the same discharge. Volume concentration of sand in suspension is reduced from 0.0820 to 0.0337, and the change in the flux of sand in suspension is −0.004 m^3/s. At this rate, sand falling out of suspension would fill a 1-m long segment of the ditch within about 20 s. Deposition of sand within the ditch reduces the conveyance capacity of the ditch, forcing water out of the ditch onto adjacent hill slopes, which would in turn force the runoff toward the side canyon that borders the study area on the east. It follows that the observed surface soils and topographic conditions located north of Mummy Lake would have interfered with the delivery of runoff from the agricultural fields by almost instantaneously clogging the ditch, preventing most of the runoff from reaching Mummy Lake.

2.2.4. Lack of evidence that Mummy Lake and the three ditch segments were components of a water gathering and distribution system

The hydrologic, topographic, and sediment transport data presented above do not support the existence of a hypothetical feeder ditch emanating from collection and gathering areas north and

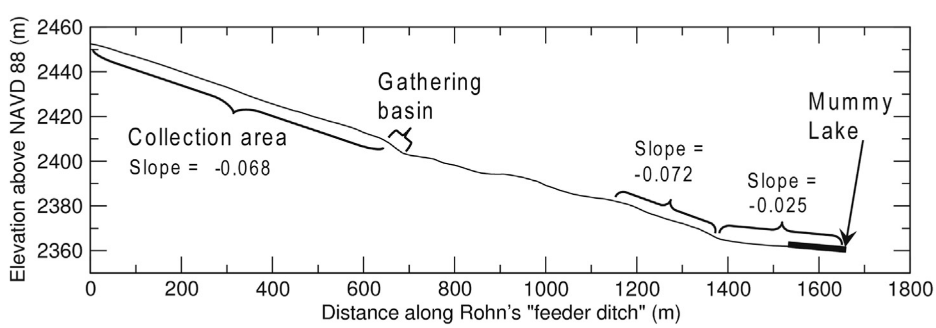

Fig. 14. Profile along the hypothetical feeder upper-ditch determined from the 10-m DEM and from the high-precision GPS survey (thick line running from 1550 to 1650 m). Total elevation drop along the 1650-mlong ditch from the upper collection area to Mummy Lake is about 91 m.

upslope of Mummy Lake. If the upper ditch had existed, it would have rapidly filled with sediment during a rain event. This would have diverted ditch water away from Mummy Lake to the canyon that borders the east side of the study area.

By itself, the small watershed area encompassing Mummy Lake provides little water to the stone-walled structure. In fact, a water-balance calculation indicates that during a typical year, water remaining in Mummy Lake in March evaporates by the end of April, and that, during the most exceptional wet year on record, water would have accumulated to a depth of 24.6 cm in by the end of April, only to have evaporated by the end of July.

Mummy Lake never held sufficient water to fill the middle ditch that terminates near the unexcavated great kiva (Fig. 2). In addition, any overland flow reaching the middle ditch would have drained from it, given its east sloping cross section (see Fig. 10). Lastly, the lower ditch that runs south from Pipe Shrine House follows a ridge line for most of its length, a topographic position that does not allow the ditch to gather water from side slopes bordering the ridge. Therefore, we suggest that Mummy Lake and the three ditch segments do not comprise an ancient water gathering and distribution system.

3. The Chapin Mesa ritual landscape

Given that Mummy Lake was not part of a water storage/distribution system and that the ditch system running from it to Cliff Palace/Spruce Tree House is not a canal system, what purpose did Mummy Lake and the ditch system serve? We offer the hypothesis that Mummy lake and the ditch system were part of a ritual landscape wherein the ditch system is a processional pathway (Chacoan road) connecting an unroofed ceremonial structure (Mummy Lake) with the Far View group. The pathway also connects Far View group to Cliff Palace/Spruce Tree House and Sun Temple.

3.1. *Mummy Lake: an unroofed ceremonial structure*

We suggest that Mummy Lake was an unroofed ceremonial structure, commonly referred to as an unroofed great kiva. Examples of such structures are listed in Table 4. Earl Morris in 1934 declared that Mummy Lake was not a kiva given its lack of distinctive PII floor features (e.g., Fig. 3.4 in Lekson, 1984); however, neither Mummy Lake nor most of the PIII unroofed kivas have been fully excavated, so we do not know what (if any) floor features were usually associated with such structures. While many of the unroofed great kivas were constructed during the PIII period, some were constructed during the PII period; e.g., Cox Ranch, Cerro Pomo, Cothrun's, Hough's, and Site AZ P:16:160 kivas (Table 4).

Table 4
Partial list of possible unroofed ceremonial centers.

Site name	Location	Reference
Atsee Nitsaa	Manuelito Canyon	Fowler et al. (1987)
Cerro Pomo Kiva	Cerro Pomo	Duff et al. (2008)
Cothrun's Kiva	Silver Creek	Herr (2001)
Cox Ranch Kiva	Cox Ranch	Duff (2004)
False Kiva	Canyonlands National Park	Images for False Kiva (2013)
Hinkson Site	Zuni Reservation	Kintigh et al. (1996)
Hough's Great Kiva	Silver Creek	Herr (2001)
Hubble Corner	Mariano Mesa	Fowler et al. (1987)
Kiva 12	Pecos	Head (2002)
Kiva F	Gran Quivira	Vivian (1964)
Kiva I	Paa-ko	Lambert (1954)
Los Gigantes	El Morro	Schachner and Kintigh (2004)
Los Gigantes	El Morro	Fowler et al. (1987)
McCreery Kiva	Petrified Forest National Park	Burton (1993)
Site 143	Hubble Corner	McGimsey (1980)
Site AZ P:16:160	Silver Creek	Herr (2001)
The Amphitheater	Wupatki National Monument	Fewkes (1926)
Village of Great Kivas	Zuni Reservation	Fowler et al. (1987)

Mummy Lake is similar in size to a 34-m diameter PIII depression found at the Hinkson site near Zuni, New Mexico. This structure has been characterized as an unroofed great kiva, and limited excavations at this site failed to reveal elaborate floor features typical of Chacoan structures (Kintigh et al., 1996). The only large unroofed PIII circular structure we know of that has been nearly fully excavated is a 20-m diameter circular depression at site 143 on the Mariana Mesa of west central New Mexico (McGimsey, 1980), and the only floor features found at this site were four cists.

The amphitheater at Wupatki is another excellent example of a PIII unroofed great kiva. This walled structure is 15.2 m in diameter and open at one end (Fig. 15A). This structure was previously deemed to be a reservoir by Fewkes (1904). No floor features were found at this site. Therefore, the PIII Mummy Lake structure and other large unroofed PIII circular structures may reflect a post-Chacoan cultural transformation away from roofed ceremonial structures with elaborate floor features (Stein and Lekson, 1992). At this time we do not know the exact configuration of the PII Mummy Lake structure. Whether it contained floor features and (or) a roof remains unknown.

Mummy Lake also resembles the post-Chacoan Wupatki ball court (Fig. 15B), which Fewkes (1904) also thought to be a reservoir. The Wupatki ball court is oval in shape, 23.4 m wide, 30.6 m long, and surrounded by a 1.8-m-tall wall. It is the only known masonry ball court in the American Southwest. Both structures (Mummy Lake and the Wupatki ball court) have embankments bounded by masonry walls; however the Wupatki ball court is separated into two lobes by gaps in the walled structure, whereas Mummy Lake has steps on its south end and may have had a gap at its north end. Both of these structures differ from Hohokam ball courts in the sense they have relatively low stone walls. It is unlikely that either site was a Mesoamerican-like ball court; in fact, some have doubted that Hohokam elliptically shaped structures were actually ball courts (Ferdon, 1967).

The amount of water covering the bottom of the so-called Wupatki ball court in July of 2013 (Fig. 15B) is of the same magnitude as that shown in the picture of two cowboys watering their horses in Mummy Lake in May of 1916 (Fig. 1 in Breternitz, 1999). This suggests that several centimeters of water in a walled semi-circular structure does not necessarily indicate the existence of a reservoir.

That Mummy Lake was ritual in nature is supported by analysis of ceramic pottery found at the site. Breternitz (1999) demonstrated that utility pottery (gray wares and corrugated shards) constituted only 13% of the Mummy Lake collection whereas decorated pottery (including white ware shards) made up 87% of the collection. In contrast, five habitation sites within about 3 km of Mummy Lake produced 43–63%, 55%, 56–74%, 67%, and 74% utility pottery (Hewitt, 1968; Jennings, 1968; Lister, 1964, 1965, 1966). The ratio of decorated to utility pottery at Mummy Lake does indicate that pottery use (at least breakage) at this site was out of the ordinary. This pattern typically is interpreted as indicating some type of "feasting" and it's likely that this kind of usage is associated with social gatherings that have some kind of ritual context.

3.2. *Chacoan ceremonial roads*

In line with the concept of Mummy Lake as a ritual structure, we suggest that the middle and lower ditches were actually ceremonial roads or processional avenues that connected, respectively, Mummy Lake to Far View group and the Far View group to Spruce Tree House/Cliff Palace. They certainly are not canals and their

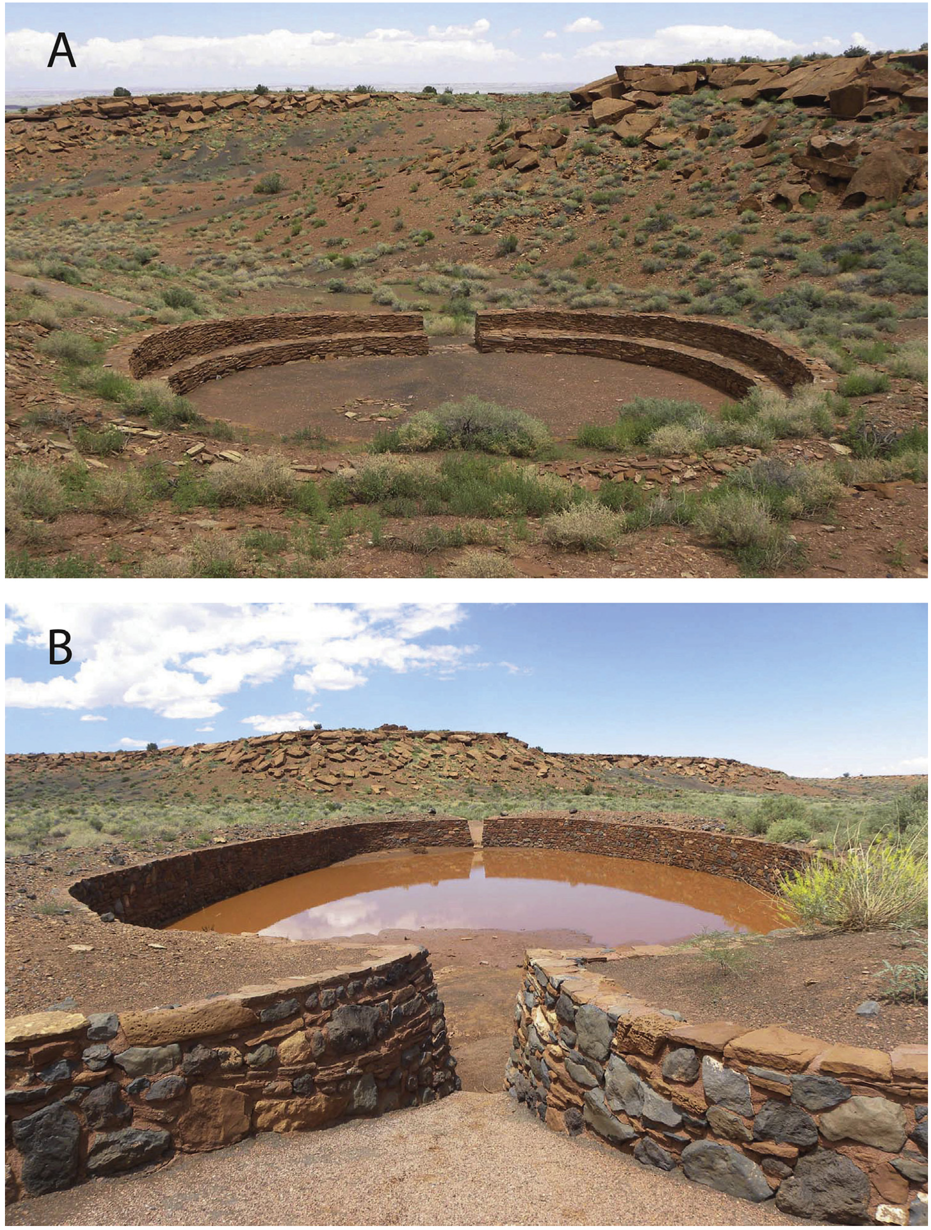

Fig. 15. Pictures of A. Wupatki amphitheater and B. Wupatki ball court. Note the standing water in the ball court, which is obviously not a reservoir.

dimensions are similar to Chacoan roads that occur elsewhere in the San Juan Basin (Stein, 1983).

The processional avenue may have split into three branches when approaching Mummy Lake from the south. Access to Mummy Lake may have been from: (1) the southward dipping slope on the east side, the steps on the south side, or the north-sloping ramp on the west side. We note that the so-called intake system/settling basin at the south end of the west ramp (Fig. 7) probably is a herradura, a horseshoe-shaped feature commonly found along Chacoan roads (Kincaid et al., 1983). Possible road shrines exist at the end of the lower ditch and just south of the herradura at Mummy Lake.

3.3. The Chapin Mesa ritual landscape mimics the Anasazi ritual landscape model exemplified by the Manuelito Canyon Community

Everything Anasazi since the 9th century is arguably Chacoan but these terms describe a pattern that is ideological-political rather than ethnic or strictly cultural. The Far View group may have been constructed by and for local Mesa Verdeans, but in essence, it is a classic Chacoan great house community and is a component of a Chacoan ritual landscape. The Far View group began construction at about the same time as Pueblo Bonito in Chaco Canyon (Windes, 2003). In addition, the Chimney Rock community, which is located 100 km east of Far View and 130 km north of Pueblo Bonito, may also have begun construction on or about A.D. 890 (based on four unpublished vv dates from the Tree Ring Laboratory, University of Arizona that range from A.D. 872 to A.D. 898). Thus, these three sites indicate some of the first manifestations of the future Chacoan domain.

Fowler and Stein (1992) developed a model of the Anasazi Ritual Landscape based on their survey of the Manuelito Canyon Community located about 130 km southwest of Chaco Canyon. In Manuelito, the ritual focus of the community was relocated several times between about A.D. 500 and A.D. 1250–1300 (The sequence of Manuelito community relocations with time is described in

Supplementary Appendix 1). At Manuelito, principal structures of the evolving ritual landscape (great houses and great kivas), once retired, remain connected to the new complex by highly formalized broad avenues.

In the case of Far View, the ritual focus of the community may have been relocated from the Far View group to Spruce Tree House/Cliff Palace and Sun Temple between A.D. 1225 and A.D. 1250 (Fig. 3). Mummy Lake and the postulated Far View great kiva are connected by means of a broad constructed processional way (the middle ditch). Far View/Pipe Shrine is, in turn, connected to Spruce Tree/Cliff Palace and Sun Temple (no cutting dates are available for Sun Temple) by a continuation of the constructed processional way. This section of the processional way has historically been described as the Far View Ditch (Rohn, 1963) or the Old Indian Ditch (Stewart, 1940) and was, for the purposes of this study, termed the lower ditch.

A changing climate may account for the pauses in construction and population shifts on Chapin Mesa during the 12th and 13th centuries (Fig. 3). Major droughts occurred in the Mesa Verde region between A.D. 1130 and A.D. 1180, between A.D. 1215 and A.D. 1245 and again between A.D. 1275 and A.D. 1300 (Fig. 9). The decline of the Far View group would appear to be associated with the first drought, the movement of the Far View community to cliff houses was associated with the second drought, and the abandonment of the cliff houses would appear to be associated with the late-13th century drought, which is also associated with abandonment of all Anasazi communities in southwest Colorado. In addition, the ritual focus of the Far View/Pipe Shrine community probably shifted from Mummy Lake to Sun Temple at about A.D. 1225.

4. Summary and conclusions

The Far View group and Mummy Lake are situated along a ridge on Chapin Mesa in Mesa Verde National Park. Tree-ring dates on the Far View group of structures indicates that construction began sometime prior to A.D. 875, was paused during the middle-12th century drought, and ended at A.D. 1250 shortly after a drought that occurred between A.D. 1215 and A.D. 1245.

Mummy Lake was constructed in two phases. Ceramics from the site indicate that the first phase of construction occurred sometime between A.D. 900 and A.D. 1150 and the second phase of construction occurred sometime between A.D. 1150 and A.D. 1300. Thus, the construction of Mummy Lake is coherent with the construction of Far View House.

In the past, it was hypothesized that Mummy Lake functioned as a water storage feature fed by a hypothetical upper ditch which emanated from a collection area located 1.2 km north of Mummy Lake. This ditch, which runs along a ridge, was thought to have been created by prehistoric Native Americans, whose feet had beaten a path from their maize fields to the reservoir, thereby creating a conduit for surface-water flow to the reservoir. No evidence of this path exists. Sediment-transport calculations coupled with the creation of a seamless elevation model, suitable for hydrologic analysis, indicate that a change in slope of the land surface some 250 m uphill from Mummy Lake would result in sediment filling the hypothetical ditch within a matter of seconds during a storm. The sediment would have then forced the water out of the ditch over the cliff edge.

Using historical climate data and topographic data resulting from a high-precision GPS survey, it was determined that, during a typical year, water would have been evaporated from Mummy Lake by the end of April. Thus, it appears that Mummy Lake was not a water storage feature or part of a larger water distribution system.

There are two other ditches in the study area. One (the middle ditch) runs from the south end of Mummy Lake to just east of Far View House, terminating near what appears to be an unexcavated great kiva just east of Pipe Shrine House. The other ditch (the lower ditch) runs from the south wall of Pipe Shrine House south along a ridge and branches just prior to reaching Spruce Tree House. We consider these ditches to be ceremonial avenues. Neither ditch would have been capable of collecting and distributing water. The middle ditch is located on the bedrock edge of the mesa and water in it would have spilled over the canyon edge. The Lower ditch lies along a ridge crest and would not have been able to collect water from either side of the ridge crest. Both ditches are much too wide and deep for the amount of surface water runoff generated by available precipitation. The lower ditch would appear to connect to Spruce Tree House/Cliff Palace, and Sun Temple. Tree-ring dates for the two cliff houses indicate that construction began about A.D. 1225 and was terminated at A.D. 1300 by the late-13th century drought.

We suggest that the Mummy Lake, Far View group, Cliff Palace/Spruce Tree House, and Sun Temple structures, along with the ceremonial roads that connect them, were components of a ritual landscape in the sense of the Manuelito Canyon model suggested by Fowler and Stein (1992), where the roads served as “umbilicals” of sacred space, connecting the present community to its past location.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.01.021.

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Supplementary Appendix 1

A review of the evolution in time and space of the Manuelito Community

In Manuelito Canyon, there are five great kivas in three ritual landscapes which represent the entire continuum of Anasazi development From A.D. 500 to A.D.1300. The phases of the ritual landscape design and construction are distinguished by distinct changes in architecture and ceramic design. At Manuelito, the principal structures of the evolving ritual landscape, the great houses/great kivas, once retired, are connected to the new complex by highly formalized broad avenues. The old complex and its replacement while sequent, may be spatially separated by a few meters to a few kilometers. Referencing the survey data that is currently available for Manuelito Canyon (Fowler et al., 1987) we find that the Basketmaker era landscape (A.D. 400-600) underlies the Post-Chaco landscape (Atsee Nitsaa, A.D. 1150-1250). A distinct post-Basketmaker/Classic Chaco era landscape (Kin Hocho'i, A.D. 650-950 and A.D. 950-1150),evolves in place with the post-Basketmaker great kiva articulated with the Chaco Era great kiva several hundred meters apart and articulated by a broad avenue. A post-Chaco era landscape (Atsee Nitsaa, A.D. 1150-1250) is several kilometers distant from Kin Hochoi but connected to the earlier landscape by means of a highly formalized alignment that also preserves the principal axis of the earlier center. The Big House era landscape (Big house/Natanii Bikin, A.D. 1250-1300) differs radically in overall form from the earlier centers but incorporates the familiar architectural vocabularies of these centers into two structures. Big House is a great house/great kiva incorporated into a single massive construction that has a fortified entry. Natanii Bikin is a contemporary tower/platform/kiva facility that overlooks Big House and is also massive and finely finished. Big House and Natanii Bikin are also linked to the earlier center at Atsee Nitsaa by means of a formalized avenue.

Kin Hocho'i, the Chaco period great house at Manuelito Canyon is comparable in size and contemporary in time with Far View House. Spruce Tree House and Cliff Palace/Sun Temple are contemporary with Big House/Naatanii Bikin in Manuelito Canyon. Further, the temporal-spatial

relationship between Cliff Palace and Sun Temple is similar to the temporal-spatial relationship between Big House and Naatanii Bikin suggesting that Sun Temple and Naatanii Bikin are analogous structures.

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Supplementary Fig. 1.

Pipe Shrine House is in the foreground and Far View House is in the background.

Supplementary Fig. 2.

Stairs at the south end of Mummy Lake.

Supplementary Fig. 3.

The middle ditch (ceremonial road) near its termination just below the south end of Mummy Lake. White lines outline the sides of the ditch. The ditch may have branched to any or all of three entrances to the Mummy Lake ceremonial structure.