1-7-2020

Prehistoric Chaco Canyon, New Mexico: Empty Pilgrimage Center of the Anasazi Hegemony

Larry Benson

John R. Stein

Richard W. Loose

Prehistoric Chaco Canyon, New Mexico: Empty Pilgrimage Center of the Anasazi Hegemony

Larry V. Benson, John R. Stein, and Richard W. Loose

This is an unpublished manuscript having a DOI of:

10.13140/RG.2.2.30889.95842

Larry V. Benson Museum of Natural History, University of Colorado-Boulder, 602 Pine St., Boulder, CO 80302, USA. (great.basin666@gmail.com, corresponding author)

John R. Stein PO Box 3044, Gallup, NM 87305, USA

Richard W. Loose PO Box 278, Organ, NM 88052, USA

Chaco has long been considered a semi-urban environment where elites residing in great houses oversaw the labors of approximately 2,000 individuals occupying small *houses on Chaco's valley floor. Recent studies cast doubt on the Canyon's ability to provide sufficient meat and maize to sustain a population this large and indicate that archaeological maize and archaeofauna found in the Canyon came from the periphery of the San Juan Basin. An alternative model for Chaco is hereby proposed wherein it was a largely vacant monumental complex to which people from outlying areas made pilgrimage along ceremonial roads. The great and small houses in the Canyon were built by visitors for their use during pilgrimage. The religious nature of Chaco is reinforced by the fact that its architectural complex was primarily constructed for ritual expression and public image with buildings situated so as to conform to the movement of celestial bodies.*

Keywords: Chaco Canyon; pilgrimage; chiefdoms; ceremonial roads; lunar and solar cycles

In this paper an alternative conceptual model of the political and religious/ceremonial nature of Chaco is outlined. The form of the model is largely dictated by the location of the environments that permitted production of maize and harvesting of meat as well as the religious and ceremonial practices of the Chacoan people.

During the past century, Southwestern archaeologists have offered a variety of conceptual models regarding the political and ceremonial nature of the Anasazi Chacoan system within the San Juan Basin. Stein and Lekson (1992) were among the first to emphasize that the carefully constructed Chacoan landscape was ritual in nature and represented the connectivity of outlying communities with the Canyon. Both Lekson (1999) and Van Dyke (2007) have suggested that landscape is essential in understanding Chaco and Van Dyke (2007) has suggested that the landscape is highly symbolic and key to understanding Chacoan politics. In addition, she proposed that people from outlying communities visited Chaco and participated in ceremonies that legitimized the political power of Canyon elites.

In recent papers, Benson and Grimstead (2019) and Benson et al. (2019) showed that Chaco Canyon was not able to support a residential population of a few thousand. If 2300 people lived in the Canyon year-round, the only alternative was to supply food from outlying productive areas. This would require at least18,000 annual treks of up to 100 km by porters carrying 44 kg of meat and maize. This paper offers another possibility – that Chaco was essentially a vacant ceremonial center, built by visitors for their use during pilgrimages and that elites associated with the great houses lived in more productive areas at the periphery of the San Juan Basin.

Conceptual Models of the Chacoan Landscape, a Brief Review

Three features of the San Juan Basin's built landscape will be highlighted in the following section of this paper: 1) Chaco Canyon with its several great houses and numerous small houses, 2) outlying communities having Bonito-style architecture, and (3) roads connecting Chaco Canyon to outlying communities at the periphery of the San Juan Basin.

Chaco Canyon

Chaco's Architecture and Residential Population

A dozen great houses lie within the confines of Chaco Canyon. The great houses are characterized by core-and-veneer masonry, numerous and extraordinarily large rooms, multiple stories, great kivas, enclosed surfaces and elevated kivas (Vivian 1990). With the assumption that Chaco's great houses were analogs to contemporary pueblos, early population estimates for Chaco Canyon were made by correlating modern Pueblo populations with room number, floor, and structural area of said Pueblos and applying that information to Chacon great houses (Drager 1976; Stubbs 1950). The combination of great house and small house population estimates (Hayes 1981) yielded a total 11th-century estimated population of ~6,000.

Chaco's Function and Purpose

The commonly held view of Chaco is that during its heyday (1050-1130 CE) it was a city with a few thousand residents, the great majority of whom lived in small houses on the Canyon valley floor, with elites occupying the several great houses (Bernadini 1999;

Lekson 1991; Windes 1987). In contrast, Toll (1985) suggested that Chacoan sites were not intended for full-time residence nor were great houses built for elites; instead, he believed they were constructed for gatherings of people from outlying communities. In addition, Judge and Cordell (2006) suggested that people living outside Chaco may have constructed, maintained, and owned some of the structures in Chaco, including great houses and communal great kivas.

Early models envisioned Chaco as a political and socio-economic hub where Chacoan elites governed a regional trade and redistribution center (Judge 1989; Sebastian 1992); however, some Chaco scholars consider Chaco to have served as a seasonal pilgrimage center for residents from outlying communities (Judge 1984, 1989; Malville and Malville 2001; Toll 1985, 1991; Windes 1987).

Several Chaco scholars (Fowler and Stein 1992; Fritz 1978; Lekson et al.1988; Sofaer et al.1989, 1991; Stein and Lekson1992) proposed that Chaco's architectural complex was primarily constructed for ritual expression and public image. Earthen architectural components at Chaco include leveled and paved surfaces, platform mounds, causeways, and ramps (Stein et al. 2003; Stein and Lekson 1992; Toll 1985; Windes 1987) as well as flat-topped pyramids (Stein et al. 2007). Stein and Lekson (1992) also suggested that the placement and design of buildings in the Canyon were related to the Chacoan's view of the universe as revealed in the movements of celestial bodies. In following years, Anna Sofaer and colleagues (Sofaer et al. 1979, 1982, 1987a, 1987b, 1989, 1991; Sofaer 2007) confirmed and expanded on the proposals of Lekson et al. (1988) and Stein and Lekson (1992), showing that the architecture of

Chaco Canyon is aligned with lunar and solar azimuths. Twelve of the principal Chaco structures are oriented to the extremes of lunar and solar cycles and the markings of light collimated by three rock slabs near the top of Fajada Butte mark the summer and winter solstices, the spring and autumn equinoxes, and the lunar major and minor standstills. In addition, Sofaer et al. (2016) have shown that 12 masonry structures (shrines) located on elevated landforms in and near Chaco Canyon, having inter-site alignments up to 15 km, are also aligned with lunar standstills. Thus, Sofaer and her colleagues have firmly documented the relation of Chacoan architecture to solar-lunar cosmology and have substantiated the religious and ceremonial nature of Chaco Canyon. It has been suggested by Judge and Malville (2004) that ceremonial events and pilgrimages to Chaco were associated with the astronomical alignments of Chaco Canyon's architecture.

Some of the shrines within the Canyon discussed by Sofaer et al. (2016) appear to constitute a signaling network that provided nearly instantaneous communication across the San Juan Basin (Hayes and Windes 1975) and possibly also to sites in southern Colorado such as Chimney Rock and Far View.

Outlying Communities

By the mid to late-11th century, numerous outlying sites appeared across the San Juan Basin and parts of northeast Arizona, southeast Utah, and southwest Colorado. A number of Southwest archaeologists including: Martin (1936), Morris (1939), and Roberts (1932) recognized the existence of such outlying communities beginning in the 1930s. The seminal study of outlying communities was done by Marshall et al. (1979)

who documented 33 major great house sites, 68 great kivas, and numerous road segments within the San Juan Basin. Two decades later Lyons and Stein (1992) reported on approximately 275 outlying sites, some of which postdated the abandonment of Chaco Canyon in 1130 CE. Today approximately 230 Chaco-era outlying great house sites are recognized (Kantner 2003; Kantner and Kintigh 2006; Van Dyke et al. 2016).

Most outlying great houses are associated with a surrounding community of small sites and were built to emulate Chaco, especially in terms of the Canyon's architecture (Van Dyke 1999). Each site contains a great house having multiple stories which was constructed using core-and-veneer masonry. In addition, great kivas and earthworks may be present. Marshall et al. (1982) distinguished early large and dispersed outlying communities occupied prior to 1050 CE from later small communities that were concentrated near their great house.

In her study of 55 great houses in 61 outlying communities, Van Dyke (1999) observed that Chacoan outlying sites were not architecturally homogeneous. Sometimes they closely resembled Canyon great houses, but at other times they appeared to represent a more local architectural concept.

Roads

S.J. Holsinger (1901) appears to be the first to firmly document and report on a Chacoan road, having observed a road segment linking Pueblo Alto with Chetro Ketl in Chaco Canyon. Road widths have been reported ranging from 2.5 to 12.6 m in width

(Holsinger 1901; Lyons and Hitchcock 1977) with road widths at major outlying sites tending to be wide.

Prior to the studies of Neil Judd in the 1920s (Judd 1954, 1964), the existence of prehistoric roadways within the San Juan Basin was widely accepted with some investigators believing the roads were purposed for transportation, including the transport of logs to Chaco Canyon (Kincaid et al. 1983). See Stein (1989) for a discussion of early historic observations of the roads.

Several studies, beginning as early as 1973, documented the existence of prehistoric road segments within the San Juan Basin that were located near Chacoan outlying communities. This led to the suggestion that many outlying sites were linked to Chaco by roads. Kincaid et al. (1983) and Powers et al. (1983) suggested that the principal Chacoan road network consisted of five roads leading from the Canyon to widely spaced resource areas located on the periphery of the San Juan Basin. Outlying communities that exploited these resources and exported them to Chaco Canyon should tend to lie at the endpoints of each road system. Indeed, such roads actually branch near their terminations at the periphery of the San Juan Basin, thus tying into numerous large outlying sites located in more environmentally rich and agriculturally productive areas (Figure 1). Kincaid et al. (1983), Loose (1979), and Powers et al. (1983) suggested that the Anasazi may have farmed at the periphery of the San Juan Basin in order to maximize maize yields. In addition, materials such as timber, chert, and ceramics were brought to Chaco from outlying areas, especially from the Chuska

Slope (Betancourt et al. 1986; Cameron 2001; English et al. 2001; Guiterman et al. 2016; Reynolds et al. 2005; Toll 2001).

Judd (1954) termed the roads in Chaco Canyon “ceremonial highways” implying that he viewed the roads not only in terms of transportation avenues but also as religious in nature. Obenauf (1980) later noted that religious integration of groups within the San Juan Basin would have been enhanced by a road network if Chaco was considered a ceremonial center.

Nials et al. (1987) demonstrated that three types of structures are visibly articulated with road surfaces: great houses, great kivas, and herraduras. Nials et al. (1987) found that herraduras were extremely useful in extending and connecting known road sections in the San Juan Basin. Herraduras are located close to road surfaces at major breaks in topography where extended visibility in both directions is assured and located. They are consistently circular or horseshoe shaped and range in diameter from 3-12 m. Most herraduras open to the east and are often associated with low-density scatters of ceramics that are usually found where the road surface is deeply excavated into bedrock. Ceramic ages suggest they were constructed in the late-11th and early-twelfth centuries and may have functioned as waypoint shrines.

Agricultural Productivity and Mammal Abundance in Chaco Canyon

Agricultural Productivity

The agricultural productivity of Chaco has been a point of contention for some time. Given that Chaco Canyon has been considered the home of a few-to-several thousand residents; a question arises regarding how they obtained their food. Although some early Southwest scholars suggested the Anasazi farmed at the wetter periphery of the San Juan Basin (Judd 1954; Kincaid et al. 1983; Loose 1979, Powers et al. 1983), many have continued to argue that the greater Canyon area was sufficiently productive to feed a large number of people, if water management systems had been implemented.

There have been a substantial number of studies (Supplementary Text 1) that have sought to demonstrate that Chaco Canyon was agriculturally productive during its heyday (1050-1130 CE). However, a recent study by Benson and Grimstead (2019) has demonstrated that Chaco Canyon's agricultural productivity was minimal and could only sustain a few hundred year-round residents. Spring flooding would have restricted farming of the wetted valley floor to <100 acres and subsequent summer floods would have destroyed or seriously damaged residual crops 85% of the time. If the entire side-valley fan area was successfully farmed, only 1150 people could be fed. Even to feed an elite and caretaker population of 300, 26% of the total side-valley area would have had to been farmed.

Benson and Grimstead (2019) also found that attempts to irrigate much of Chaco Canyon's valley floor would have entailed the construction of massive rock-armored berms and ditches, which should still be visible on the landscape. Such structures are not evident, suggesting that maize productivity within the valley floor was minimal at best during Chacoan occupation of the Canyon.

Mammal Productivity

Not only maize and beans were required by the residents of Chaco Canyon, protein in the form of meat also was necessary for survival. A worker needs, on average, 0.06 kg protein (PRT)/day to function, and if 2300 people lived in Chaco, they needed 50,370 kg PRT/yr to survive, which amounts to 167,900 kg of deer, rabbit, or other meat animals (note the value of 83,950 kg protein/yr in the Benson and Grimstead (2019) abstract is incorrect). An annual harvest of this scale would rapidly exhaust small and large mammal populations within and surrounding the Canyon. This indicates that only a few hundred people resided in the Canyon or that meat and maize were transported to the Canyon from outlying areas.

Sr-Isotope Evidence of Sources of Archaeofauna and Archaeological Cobs Found in Chaco Canyon

In order to determine possible sources of meat consumed by Chacoans, Benson et al. (2019) compared Sr-isotope data on archaeofauna extracted from trenches excavated in platform mounds in front of Pueblo Bonito (Grimstead et al. 2016) with Sr-isotope data from soils and rabbitbrush sampled within the San Juan Basin, including the Canyon itself. They showed that a number of regions around the periphery of the San Juan Basin, including the Chuska Mountain/Slope area, were likely sources of the archaeofauna, especially deer.

A comparison of Sr-isotope data on pre-1130 CE archaeological cobs from the Canyon with soil and rabbitbrush data was insufficient to demonstrate whether the cobs had a Canyon or an extra-Canyon source. However, given the minimal agricultural productivity of the Canyon (Benson and Grimstead 2019), the data strongly suggest a

Chuskan source. In addition, Benson et al. (2019) showed that snowmelt runoff from the Chuska Mountains to the Chuska Slope had the potential to provide nearly 30,000 people with their annual maize requirement.

The Effort Expended in Supplying 2300 Canyon Residents with Meat and Maize

If 2300 people lived in the Canyon, and if the Canyon environment could not provide sufficient meat and maize to sustain such a population, then such food would have to be imported, involving a substantial amount of labor. One consequence of supplying food to residents of Chaco is that it would take 18,000 annual trips by porters carrying 45 kg of meat and maize from outlying areas to supply such a population (Benson et al. 2019). This represents a significant amount of man power. For example, if all the porters came from the Chuskas, which had an estimated population of ~11,000[1] (Heilen and Leckman 2014), then 18% of the male workforce would have had to have been diverted to feed Chacoan residents. Porters from other areas around the periphery of the San Juan Basin could also have been tasked for importation of food, thus alleviating the strain on Chuskan manpower. However, another possibility exists that negates the manpower requirement involved in food importation; that is, there were only a small number of people that actually resided in Chaco Canyon.

Chaco Canyon Burials Indicate a Small Canyon Residential Population

One way of determining the standing population of Chaco is to use burial number. Information to date has not documented the practices of cannibalism or cremation in

[1] Assumes families with five members

Chaco so those practices can be discounted. 578 burials have been documented in Chaco that date between 850 and 1130 CE (Akins and Schelberg 1984; Akins 1986 2001). Using death rates for 32 African third-world countries (World Statistics 2012), the average population that accounts for the number of Chaco Canyon burials was calculated. The mean-annual death rate was found to range from 1.29 to 2.50% of the population/yr with a mean overall death rate of 1.83% of the population/yr. These rates were applied to the number of bodies exhumed from Chaco Canyon and it was found that a population of 83 to 160 individuals with an average residential population of 113 would account for all burials occurring between 850 and 1130 CE.

A residential population of 2300 individuals should have resulted in 8300 to 16,000 burials. Clearly there are unexcavated remains of additional Chacoans within the Canyon, but the number that have been exhumed to date argue against an average residential population of 2300. This is consistent with Windes et al. (2000) who suggested that the lack of bodies in the Chaco Canyon area indicate a mobile, transient population that spent far less time there than cultural remains suggest.

Small House Occupation: A Different Interpretation

The principal argument for at least 2,000 permanent residents in Chaco is the presence of small houses (Hayes 1981). Only a small sample of small house sites has been excavated, and furthermore, the assumption of long-term continuous occupation is based on the unstated conditional assumption that if surface scatters (or excavated small houses) contain artifacts with P I, P II, and P III characteristics, then the site was continuously occupied from P I through P III. This assumption ignores the possibility that ceramic scatter represents discontinuous occupation during each of those categorical time periods.

Small houses may have been intended for the use by visitors on pilgrimage and thus were only occasionally occupied. If visiting families occupied a small house once a year for the 80 years between 1050 and 1130 CE, a great quantity of broken ceramic material would have accumulated, which could be interpreted incorrectly as evidence of continuous occupation. This conclusion is consistent with the argument of Windes et al. (2000) that neither small nor great houses have been demonstrated to have been continuously occupied.

Some Thoughts Regarding Chaco's Role as a Pilgrimage Center

What is a pilgrimage center? To our way of thinking it is a special place that a large number of people come to engage in several possible activities, from utilitarian to religious, hierarchical to communal, and private to public with no likely clear delineation between. It can be a place where special ceremonies are observed, where disputes between different groups are resolved, where celebration and feasting occur, and where mating pools are arranged. These centers are imbued with power and significance by their ritual landscapes, historical importance and/or origins, and the personal, economic, and/or ritual cost to reach (Kantner and Vaughn 2012; Malville and Malville 2001; Preston 1992).

Toll (1985) was one of the first to propose that people from outlying areas regularly gathered in Chaco for rituals and feasting based on his ceramic analysis of the trash mound at Pueblo Alto. Identifying feasting in the archaeological record necessitates certain criteria, including associations with unique architectural features, clear isolated depositions, and unique debitage from the mundane to the rarity in type, quantity or disposal (Grimstead and Bayham 2010; Hayden 1996; Pauketat et al. 2002). Before the work of Toll (1985), Tom Windes led an excavation of the Pueblo Alto complex, including the mound at the complex, and concluded the layered regularity of the deposit and the apparent agreement between layer number and the period of deposition suggested deposition was an annual event (Windes (1987). Toll (2001) later agreed with Windes' conclusion, suggesting that stratigraphic discontinuities existed between material accumulations indicating a lengthy series of periodic gatherings (but see Wills 2001; Plog and Watson 2012).

Lekson et al. (1988) has pointed out that some of the features of Chaco Canyon great houses indicate a relatively small residential population and that it may have been a ceremonial center, serving the needs of outlying groups. Some of those features include the relatively small number of habitation rooms and the intermittent deposition of cultural material as previously noted by Toll (1985) and Windes (1987). Thus, stratigraphically layered materials derived from periodic feasting comprise a significant part of the fabric of the great mounds and may appear in other contexts at Chaco.

There are a substantial number of material imports from outlying regions to Chaco that support the concept of a pilgrimage center. For example, architectural timbers were brought from the Chuska Slope and Zuni Mountains (Betancourt et al. 1986; English et al. 2001; Guiterman et al. 2016; Reynolds et al. 2005), Narbona chert and corrugated gray ware were imported from the Chuska Slope (Cameron 2001; Toll 2001), and maize and animals came from areas outside the Canyon (Benson 2010, 2012; Benson and Grimstead 2019; Benson et al. 2019). Cameron (2001:98) in her study of exotic stone materials found in Chaco Canyon stated

> "The deposit of literally hundreds of projectile points at rooms in Pueblo Bonito seems likely to have been another aspect of the ritual activity connected with the Chacoan Regional System, one that fits well with Renfrew's view of Chaco as a location of High Devotional Expression. Chipped-stone data support the suggestion made by Earle (2001), Peregrine (2001), Renfrew (2001) and others (Judge 1979; Loose and Lyons 1977; Toll 1985) that great houses in Chaco Canyon were the focus of periodic communal gatherings."

In a recent paper, Guiterman et al. (2020) employed documentary evidence, Sr isotopes, and tree-ring sourcing to show that the Plaza Tree from the Pueblo Bonito plaza did not grow there nor was it from the Chaco Canyon area. Instead, the 250-yr old ponderosa pine, that died sometime after 981 CE (based on an outer ring vv+ date) originate in the Chuska Mountains. The placement of this tree may express symbolically a connection between the Chuskan people and Chaco Canyon, and, in particular, a connection of the Chuskan people to the Pueblo Bonito great house. It may also signal that the Chuskas would begin to act as the principal source of timbers brought into Chaco in order to build new great houses and modify the three original ones.

Chaco may also have served as a trade center during pilgrimage. Maize, beans, and dried or smoked meat brought in by communities on the periphery of the San Juan Basin could have been exchanged for exotic goods such as turquoise produced by other groups. In terms of possible documentation of pilgrimages to Chaco, Van Dyke (2018) identified a rock art panel at one of the major entrances to Chaco Canyon that depicts numerous footprints, perhaps indicating the movements of people during pilgrimages.

A Revised Conceptual Model of the Political Structure and Ceremonial Nature of the Chacoan System

The alternative conceptual model of the Chacoan system detailed below contains both new and old elements. The framework of this hypothetical socio-political and religious system has the following elements:

1. Only a few hundred caretakers made up the residential population of Chaco. Their principal duties included maintenance of existing structures, protection of stored foodstuffs, and care of ceremonial objects. A small residential population is consistent with the limited number of burials discovered at Chaco and, more importantly, makes unnecessary non-quantitative arguments that attempt to support the agricultural productivity of Chaco.

2. Chaco was essentially an empty architectural complex built by visitors for the use of visitors that took part in pilgrimages from outlying regions. Elites did not live year-round in Chaco and it was not an urban center. Instead it was the political, religious and social focal point of people living in outlying regions.

3. There are two areas on the north and south ends of the Chuska Slope that can be described as “Super Communities”. These areas have been densely occupied from Basketmaker times onward. They are composed of multiple great houses and great kivas, and are agriculturally productive. In the past they were linked to Chaco Canyon by constructed roadways. The Northern Super Community, the Blackhouse community (Figure 1), is focused on the Black House, Captain Tom, Tocito, and Sanostee drainages. Documented great houses/ritual landscapes in this community include, but are not limited to: Skunk Springs, Newcomb (Cemetery Ridge), Crumbled House, Toadlena, Tocito, Sanostee, and Where the Bear Jumps Up (see Figure 1 and Table 1 for locations of some of these communities). Narbona Pass Chert and trachyte tempered ceramics as well as many of the timbers used to construct Chaco great houses after 1050 CE probably came from this area. The Southern Super Community is located at the southern end of the Chuska Mountains and encompasses the land between Tolakai and Tohatchi. The community then continues intermittently eastward along the north-facing base of the Dutton Plateau to Kin Ya’ a, a first order great house connected directly to Chaco Canyon by the South Road (Figure 1).The area between the western end of the Dutton plateau and the southern end of the Chuskas is referred locally as “Tohatchi Flats”, which is

connected to Chaco Canyon by the Coyote Canyon Road (Figure 1). The Southern Super Community includes numerous great houses, including: Kin Ya'a, White Point, Muddy Water, Standing Rock, Dalton Pass, Peach Springs, Grey Ridge, Red Willow, Figueredo, and Tolakai (see Figure 1 and Table 1 for locations of some of these communities).

4. The people in outlying areas (including super communities) within and surrounding the San Juan Basin represented different language groups. For example, to the north were Tewa speaking people (Ortman 2010); to the west were the Hopi who spoke a Uto-Aztecan dialect; to the south were the Zuni who spoke an isolate language; and to the southeast were the Acoma who spoke Keresan.

5. The production and distribution of food in agriculturally productive outlying areas required an administrative system. It is suggested that heads of chiefdoms in these areas oversaw these tasks, thereby consolidating their overall authority. It is possible that these elite chiefs occupied Canyon great houses when on pilgrimage.

6. By 1050 CE Chaco was geographically a central place within the San Juan Basin surrounded by numerous outlying communities. At times, the occupants of outlying communities traveled to Chaco on pilgrimage and occupied the great and small houses they had constructed.

7. Visitors to Chaco brought timbers from the Zuni Mountains and Chuska Slope to build the great houses (Betancourt et al. 1986; English et al. 2001;

Guiterman et al. 2016; Reynolds et al. 2005) and they also played a major part in the construction of small and great houses.

8. The Chuskan region was probably the principal supplier of foodstuffs found in trenches cut into platform mounds in front of Pueblo Bonito. However, deer could have come from several other outlying sources on the periphery of the San Juan Basin. Figure 1 shows major community centers in outlying regions that may have provided meat and maze to Chaco to feed those on. A visitor to the Canyon who stayed a week need carry only 22 kg of food and water on the trip in and 14 kg of food and water on the trip out. This left room for the transport of other materials such as ceramics, chert, and ceremonial objects.

9. It is probable that the Chuskas served as the principal bread basket for the San Juan Basin and surrounding areas. The transport of construction timbers and foodstuffs from the Chuskas to the Canyon demonstrates Chuskan ties to the Canyon. The fact that a 6-m-long ponderosa was transported from the Chuskas and placed in the Pueblo Bonito plaza (Guiterman et al., 2020) suggests a Chuskan affiliation with that great house.

10. Roads from Chaco lead south to the Dutton Plateau area, southwest to Tohatchi, west to Newcomb, east to Pueblo Pintado and north to the Totah area where the Animas and LaPlata rivers meet the San Juan River (Figure 1). These ceremonial roads served to funnel and focus paths of those on pilgrimage to Chaco. In addition, they terminate at regions with Sr-isotope ratios matching ratios of archaeofauna (especially deer) recovered from trenches in Chaco

Canyon, thus tying those on pilgrimage to sources of archaeofauna found in the Pueblo Bonito trenches.

11. Visitors didn't bring ceramics, chert, ceremonial objects, and other materials as offerings to elites living in Chaco Canyon; instead, these materials were brought to the Canyon where they were stored for subsequent use by the visitors. This answers the question of why materials, in general, do not appear to have been exported from Chaco to outlying regions; the people visiting the Canyon were from outlying regions.

12. Reasons for the gatherings at Chaco will always remain a matter of speculation; the principal activities may have been dispute resolution of problems arising among outlying sites, redistribution of food and seeds to small agriculturally poor communities, and religious and political observances. After 1050 CE numerous outlying communities, exhibiting elements of Chacoan architecture, dotted the San Juan Basin (see, for example, Figure 1 in Van Dyke (2002). Some of these villages practiced dryland farming, which under the best circumstances was risky. Therefore, during times of drought these villages would have sought support from more agriculturally productive communities. In a sense, Chaco became a neutral place for people to gather and solve intra-basin problems including the allocation of foodstuffs. In addition, it may have been a place where gambling could occur without causing friction among members of small outlying community (Weiner, 2018), as gambling can be fractious and create problems within a sparsely populated community.

13. Chaco was not a city with a large residential population; it was a nearly empty ceremonial center. The “Mystery of Chaco Canyon” lies in the existence of its monumental architecture together with the presence of a rather large number of people in a desolate and inhospitable environment. The answer to that mystery is that the monumental architecture was chiefly symbolic and served as a focal point of pilgrimage from outlying areas and that the residential population of the Canyon was actually quite small.

Conclusions

This paper discusses an alternative model for the nature of Chaco. Chaco was not an urban center with elite chiefs living in great houses, and the small houses in the Canyon were not occupied year-round. Instead, Chaco is considered to have been essentially a vacant ceremonial center with most people living in more productive outlying areas, although a few hundred caretakers may have resided year-round in the Canyon.

The great and small houses in Chaco Canyon were built by people from outlying areas for their use during pilgrimages. Pilgrimages occurred along specially constructed road systems leading to a ceremonial center (Chaco Canyon) that contained structures aligned with lunar and solar events Those pilgrims may have belonged to different language groups, and elite chiefs from outlying agriculturally productive communities may have been associated with the Canyon’s great houses

Meat and maize resources in the Chaco Canyon area were minimal. Production of maize and the harvesting of meat animals occurred in more productive outlying areas at the periphery of the San Juan Basin. The leadership in those areas consolidated their authority by overseeing production and distribution of these food resources.

This paper presents an alternative conceptual model of the Chacoan system. It is a model that needs to be tested in order to determine its validity relative to the existing model of the Chacoan system, which assumes Chaco Canyon was an agriculturally productive urban center with a residential population of a few thousand individuals. We think existing information; for example, the limited number of Canyon burials, tends to support the new model but, in fact, either model may be correct. Unfortunately, this indicates just how little is known regarding the overall functioning of the Chacoan system.

Methods

The map in Supplementary Figure 1 was generated by digitizing the Scarborough's et al. (2018) canal transect using QGIS software. The geo-coordinates were latitude-longitude values derived from Google Earth. The canal route was then extracted and saved as a kmz file and the elevation of the proposed canal plotted using that file.

.

Acknowledgements. The authors thank Scott Andrae for assistance in creating the elevational plot of the Vivian canal depicted in Supplementary Figure 1, Kirk Vincent for his insights regarding the sedimentology of the two pits dug into the canal, and Eleanor Griffin with help in understanding the model presented in Dorshow (2012). We also thank Anna Sofaer for allowing us to modify Figure 9.1 in Sofaer (2007) to create Figure 1.

Data availability. No original data were presented in this paper.

Supplementary Materials. For supplementary material accompanying this paper, visit www.journals.cambridge.orgAmerican Antiquity.

References Cited

Akins, N. J.

1986 *A Biocultural Approach to Human Burials from Chaco Canyon*, Reports of the Chaco Center 9. National Park Service, Santa Fe, New Mexico.

Akins, N. J.

2001 Chaco Canyon mortuary practices: Archaeological correlates of complexity. In *Ancient Burial Practices in the American Southwest*, edited by D.R. Mitchell and J.L. Brunson-Hadley, pp. 167-190, University of New Mexico Press, Albuquerque.

Akins, N. J., Schelberg J.D.

1984 Evidence for organizational complexity as seen from the mortuary practices at Chaco Canyon. In *Recent Research on Chaco Prehistory*, edited by W.J. Judge and J.D. Schelberg, pp. 89-102, Division of Cultural Research, National Park Service, Albuquerque,

Ayers, R.S.

1977 Quality of Water for Irrigation. *Journal of Irrigation and Drainage Division* 103:115-134.

Bauer, C.M., and J.B. Reeside, Jr.

1921 Coal in the middle and eastern parts of San Juan County, New Mexico. *U.S. Geological Survey Bulletin* 716-G:77-178.

Benson, L.V.

2010 Who provided maize to Chaco Canyon after the mid-12th-century drought? *Journal of Archaeological Science 37*: 621-629.

Benson, L.V.

2012 Development and application of methods used to source prehistoric Southwestern maize: A review. *Journal of Archaeological Science* 39:791-807.

Benson L.V.

2017 The Chuska Slope as an agricultural alternative to Chaco Canyon: A rebuttal of Tankersley et al. (2016). *Journal of Archaeological Science: Reports* 16:456-471.

Benson, L.V., and D.N. Grimstead

2019 Prehistoric Chaco Canyon, New Mexico: Residential population indications of limited and agricultural and mammal productivity. *Journal of Archaeological Science* 108:104971.

Benson, L.V., D.N., Grimstead, J.R. Stein, D.A. Roth, and T.I. Plowman

2019 Prehistoric Chaco Canyon, New Mexico: Importation of meat and maize. *Journal of Archaeological Science* 111:105015.

Bernadini, W.

1999 Reassessing the scale of social action at Pueblo Bonito, Chaco Canyon, New Mexico. *Kiva* 64:447-470.

Betancourt, J.L., J.S., Dean, and H.M. Hull

1986 Prehistoric long-distance transport of construction beams, Chaco Canyon, New Mexico. *American Antiquity* 51:370-375.

Bradfield, M.

1971 *The Changing Pattern of Hopi Agriculture*. Royal Anthropological Institute Occasional Paper 30, London.

Brugge, D.H.

1980 *A History of the Chaco Navajos*, Reports of the Chaco Canter No.4. Division of Chaco Research, National Park Service, Albuquerque.

Cameron, C.M.

2001 Pink chert, projectile points, and the Chacoan regional system. American Antiquity 66:79-101.

Dorshow, W.

2012 Modeling agricultural potential in Chaco Canyon during the Bonito phase: A predictive geospatial approach. *Journal of Archaeological Science* 39:2098-2115.

Dorshow, W.

2019 3D landscape reconstruction and land use modeling, Chaco Canyon, NM 2016. National Center for Airborne Laser Mapping (NCALM), distributed by Open Topography. https://doi.org/10.5069/G9XG9P8D.

Doyel, D.E., C.D. Breternitz, and M.P. Marshall

1984 Chacoan Community Structure: Bis sa'ani Pueblo and the Chaco Halo. In *Recent Research on Chacoan Prehistory*, edited by W.J. Judge and J.D. Schelberg, pp.37-54, National Park Service, Albuquerque, New Mexico.

Drager, D.L.

1976 Anasazi Population Estimates with the Aid of Data from Photogrammetric Maps. In *Remote Sensing Experiments in Cultural Resource Studies*, edited by T.R. Lyons, pp. 157–171. Reports of the Chaco Center 1. Division of Cultural Research, National Park Service, Albuquerque, New Mexico

Earle, T.

2001 Economic support of Chaco Canyon Society. *American Antiquity* 66:26-35.

English, N.B., J.L. Betancourt, J.S. Dean, and J. Quade

2001 Strontium isotopes reveal distant sources of architectural timber in Chaco Canyon, New Mexico. *Proceedings National Academy of Sciences* 98:11891-11896.

Force, E.R.

2004 Late Holocene behavior of Chaco and McElmo Canyon drainages southwest U.S.: A comparison based on archaeologic age controls. *Geoarchaeology* 19:583–609.

Force, E.R., R.G. Vivian, T.C. Windes, and J.S. Dean

2002 *Relation of "Bonito" paleo-channels and base-level variations to Anasazi occupation, Chaco Canyon, New Mexico*. Arizona State Museum Archaeological Series 194, Tucson.

Fowler, A.P., and J.R. Stein

1992 The Anasazi Great House in Space, Time, and Paradigm. In *Anasazi Regional Organization and the Chaco System*, edited by D.E. Doyel, pp.101-122. Maxwell Museum of Anthropology, Anthropological Papers 5, Albuquerque, New Mexico.

Fritz, J.M.

1978 Ideational Systems and Human Adaptation in Prehistory. In *Social Archaeology, Beyond Subsistence and Dating*, edited by C.L. Redman, pp.37-59. Paleopsychology Today, Academic Press, New York.

Grimstead, D.N., and F.E. Bayham

2010 Evolutionary ecology, elite feasting, and the Hohokam: A case study from a southern Arizona platform mound. *American Antiquity* 75:841-864.

Grimstead, D. N., J. Quade, and M.C. Stiner

2016 Isotopic evidence for long-distance mammal procurement, Chaco Canyon, New Mexico, USA. *Geoarchaeology* 31:335-354.

Guiterman, C.H., T.W. Swetnam, and J.S. Dean

2016 Eleventh-century shift in timber procurement areas for the great houses of Chaco Canyon. *Proceedings National Academy of Sciences* 113:1186-1190.

Guiterman, C.H., C.H. Baisan, N.B. English, J. Quade, J.S. Dean, and T.W. Swetman

2020 Unearthing the story of JPB-99, the Plaza Tree of Pueblo Bonito. *American Antiquity*, in review.

Hayden, B.

1996 Feasting in Prehistoric and Traditional Societies. In *Food and the Status Quest: An interdisciplinary Perspective*, edited by P. Wiessner and W Schiefenhovel, pp. 129-147. Berghahn Books, Oxford.

Hayes, A.C.

1981 A Survey of Chaco Canyon Archeology. In *Archeological Surveys of Chaco Canyon, New Mexico*, edited by A.C. Hayes, D.M. Brugge and W.J. Judge, pp. 1–68. National Park Service Series No. 17A, Chaco Canyon Studies, National Park Service, Washington, DC.

Hayes, A.C., and T.C. Windes

1975 An Anasazi Shrine in Chaco Canyon. In *Collected papers in honor of Florence Hawley Ellis*, edited by T.R. Frisbie, pp. 143-156. Papers of the Archaeological Society of New Mexico 2, Hooper Press, Norman, Oklahoma.

Heilen, M., and P. Leckman

2014 Place, Community and Cultural Landscape: Anasazi Occupation of the Chuska Valley. In *Bringing the Basin: Land Use and Social History in the Southern Chuska Valley*. Edited by M.L. Murrell and B.J. Vierra, pp. 319–395. Synthesis, Vol. 4, New Mexico Department of Transportation Cultural Resource Technical Series 2014-2.

Holsinger, S.J.

1901 Report on pre-historic ruins of Chaco Canyon NM. Manuscript on file, National Archives, Washington DC.

Jackson, W.H.

1878 *Report on the Ancient Ruins Examined in 1877*. 10th Annual Report, U.S. Geological and Geographical Survey of Territories for the Year 1876, Washington DC.

Judd, N.M.

1954 *The material culture of Pueblo Bonito*. Smithsonian Miscellaneous Collections 124.

Judd, N.M.

1964 *The architecture of Pueblo Bonito*. Smithsonian Miscellaneous Collections 147.

Judge, J.W.

1979 The Development of a Complex Cultural Ecosystem in the Chaco Basin, New Mexico. *Proceedings of the first conference on scientific research in the National Parks, Vol. 2,* edited by R.M. Linn, pp. 901-906. Transactions and Proceedings Series 4, National Park Service, Washington.

Judge, W.J.

1984 New Light on Chaco Canyon. In *New Light on Chaco Canyon*, edited by D.G. Noble, pp. 1-12. School of American Research Press, Santa Fe, New Mexico.

Judge, W.J.

1989 Chaco Canyon - San Juan Basin. In *Dynamics of Southwest Prehistory*, edited by L.S. Cordell and G.J. Gumerman, pp. 209-262. Smithsonian Institution Press, Washington DC.

Judge, W.J. and L.S. Cordell

2006 Society and Polity. In *The Archaeology of Chaco Canyon: An Eleventh-Century Pueblo Regional Center*, edited by S.H. Lekson, pp.189-210.School of American Research Press, Santa Fe, New Mexico.

Judge, W.J. and J.M. Malville

2004 Calendrical Knowledge and Ritual Power. *In Chimney Rock: The Ultimate Outlier*, edited by J.M. Malville, pp.151-163. Lexington Books, Lanham, Maryland.

Kantner, J.

2003 Rethinking Chaco as a system. *Kiva* 69:207-227.

Kantner, J., and K. Kintigh

2006 The Chaco World. In *The Archaeology of Chaco Canyon: An Eleventh-Century Pueblo Regional Center*, edited by S.H. Lekson, pp.153-188. School of American Research Press, Santa Fe, New Mexico.

Kantner, J., and K.J. Vaughn

2012 Pilgrimage as a costly signal: Religiously motivated cooperation in Chaco and Nasca. *Journal of Anthropological Archaeology* 31:66-82.

Kincaid, C., D.F. Levine, F.L. Nials, M.S. Obenauf, B.P. Robertson and others

1983 Chaco Roads Project Phase 1. In *A Reappraisal of Prehistoric Roads in the San Juan Basin*, edited by C. Kincaid. Bureau of Land Management, New Mexico State Office, Albuquerque.

Lagasse, P.F., W.B. Gillespie, and K.G. Eggert

1984 Hydraulic Engineering Analysis of Prehistoric Water-Control Systems at Chaco Canyon. In *Recent Research on Chaco Prehistory*, edited by W.J. Judge, and J.D. Schelberg, pp. 197–212. Division of Cultural Research, National Park Service, Albuquerque, New Mexico.

Lekson, S.H., T.C. Windes, J.R. Stein, and W.J. Judge

1988 The Chaco Canyon community. Scientific American 259:100-109.

Lekson, S.H.

1991 Settlement Patterns and the Chaco Region. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by P. Crown and W.J. Judge, pp. 31-56. School of American Research Press, Santa Fe, New Mexico.

Lekson, S.H.

1984 *Great Pueblo Architecture of Chaco Canyon, New Mexico*. Publications in Archaeology 18B, Chaco Canyon Studies, National Park Service, Albuquerque, New Mexico.

Lekson, S.H.

1999 *The Chaco Meridian. Centers of Political Power in the Ancient Southwest*. Altamira Press, Walnut Creek, California.

Loose, R.W.

1979 *Research Design: Appendix to Marshall, M.P., J.R. Stein, R.W. Loose, and J.E. Novotny, Anasazi Communities of the San Juan Basin*. Public Service Company of New Mexico, Albuquerque.

Loose, R.W., and T.R. Lyons

1977 The Chetro Ketl field: A Planned Water Control System in Chaco Canyon. In *Remote Sensing Experiments in Cultural Resource Studies: Non-Destructive Methods of Archaeological Exploration, Survey, and Analysis*, edited by T.R. Lyons, pp.

133-156. Reports of the Chaco Center, no. 1, National Park Service and University of New Mexico, Albuquerque.

Love, D.W., M.L. Gillam, L.V. Benson, R. Friedman, P.L. Miller, and K. R. Vincent

2011 Geomorphology and alluvial stratigraphy in lower Chaco Canyon do not support the possible existence of prehistoric sand-dammed ephemeral lakes. *New Mexico Geology* 33:107-123.

Lyons, T.R., and R.K. Hitchcock

1977 Remote Sensing Interpretation of Anasazi Land Route System. In *Aerial Remote Sensing Techniques in Archaeology*, edited by T.R. Lyons and R.K. Hitchcock, Reports of the Chaco Center no. 2.

Malville, J.M., and N.J. Malville

2001. Pilgrimage and periodic festivals as processes of social integration in Chaco Canyon. *Kiva* 66:327-344.

Markstrom, S.

2019 United States Geological Survey Precipitation Runoff Modeling System (PRMS), https://www.usgs.gov/software/precipitation-runoff-modeling-system-prms.

Marshall, M.P., D.E. Doyel, and C.D. Breternitz

1982 A Regional Perspective on the Late Bonito Phase. *In Bis sa'ani: A late Bonito Phase Community on Escavada Wash, Northwest New Mexico*, edited by C.D. Breternitz, D.E. Doyel, and M.P. Marshall, pp. 1227-1240. Navajo Nation Papers in Anthropology 14, Window Rock, Arizona.

Marshall, M.P., J.R. Stein, R.W. Loose, and J.E. Novotny

1979 *Anasazi Communities of the San Juan Basin*. Public Service Company of New Mexico. Albuquerque..

Martin, P.S.

1936 *Lowry Ruin in Southwestern Colorado*. Chicago Field Museum of Natural History Anthropology Series 23.

McCool, J.P.P., S.G. Fladd, V.L. Scarborough, S. Plog, N.P. Dunning, N.P., L. A. Owen and others

2018 Soil analysis in discussions of agricultural feasibility for ancient civilizations: A critical review and reanalysis of the data and debate from Chaco Canyon, New Mexico. *PLoS ONE* 13:e0198290.

Missouri Extension

2019 Corn Irrigation and Water Use. http://extension.missouri.edu/scott/documents/Ag/Irrigation/Corn-Irrigation-and-Water-Use.pdf

Morris, E.H.

1939 *Archaeological Studies in the La Plata District: Southwestern Colorado and Northwestern New Mexico*. Carnegie Institute of Washington Publication 519, Washington DC.

Nials, F., J. Stein, and J., Roney

1987 *Chacoan roads in the southern periphery: Results of phase II of the BLM Chaco Roads Project*. U.S. Bureau of Land Management, Albuquerque District, Albuquerque, New Mexico.

Obenauf, M.S.

1980 The Chacoan Roadway System. Master's thesis, Department of Anthropology. University of New Mexico.

Ortman, S.G.

2010 Evidence of a Mesa Verde Homeland in the Tewa Pueblos. In *Leaving Mesa Verde: Peril and Change in the Thirteenth-Century Southwest*, edited by T.A. Kohler, T.A., M.D. Varien, M.D., and A.M. Wright, pp. 222-261. Amerind Studies in Archaeology 5, University of Arizona Press.

Pauketat, T.R., L.S. Kelly, G.L. Fritz, N.H. Lopinot, S. Elias, and E. Hargrave

2002 The residues of feasting and public ritual at Early Cahokia. *American Antiquity* 67:257-279.

Peregrine, P.N.

2001 Matrilocality, corporate strategy, and the organization of production in the Chacoan World. *American Antiquity* 66:36-46.

Plog, S., and A.S. Watson

2012 The Chaco pilgrimage model: Evaluating the evidence from Pueblo Alto. *American Antiquity* 77:449-477.

Powers, R.P., W.B. Gillespie, and S.H. Lekson

1983 *The Outlier Survey: A Regional View of Settlement in the San Juan Basin*. Reports of the Chaco Center 3. National Park Service, Albuquerque, New Mexico.

Preston, J.J.

1992 Spiritual Magnetism: An Organizing Principle for the Study of Pilgrimage. In: *Sacred Journeys, the Anthropology of Pilgrimage*, edited by A. Morinis, pp. 31-46. Greenwood Press, Westport, Connecticut.

Renfrew, C.

2001 Production and consumption in a sacred economy: The material correlates of High Devotional Expression at Chaco Canyon. *American Antiquity* 66:14-25.

Reynolds, A.C., J.L. Betancourt, J. Quade, P.J. Patchett, J.S. Dean, and J. Stein

2005 $^{87}Sr/^{86}Sr$ sourcing of Ponderosa pine used in Anasazi great house construction at Chaco Canyon, New Mexico. *Journal of Archaeological Science* 32:1061-1075.

Richert, R.

1967 Richard Gordon Vivian, 1908-1966. *American Antiquity* 32:100-103.

Roberts, F.H.

1932 Village of the Great Kivas on the Zuni Reservation, New Mexico. Bureau of American Ethnology Bulletin 111.

Scarborough, V.L., S.J. Fladd, N.P. Dunning, S. Plog, L.A. Owen, C. Carr, C., and others

2018 Water uncertainty, ritual predictability and agricultural canals at Chaco Canyon, New Mexico. *Antiquity* 92:870-889.

Sebastian, L.

1992 Chaco Canyon and the Anasazi Southwest: Changing Views of Sociopolitical Organization. In *Anasazi Regional Organization and the Chaco System*, edited by D.E. Doyel. Maxwell Museum of Anthropology, Anthropological Papers 5. University of New Mexico, Albuquerque.

Simpson J.H.

1852 *Journal of a Military Reconnaissance from Santa Fe, New Mexico, to the Navajo Country in 1849*. Report of the Secretary of War, 31st Congress, 1st Session, Senate Executive Document 64, 56–168.

Sofaer, A.

1989 An Interpretation of a Unique Petroglyph in Chaco Canyon, New Mexico. In *World Archaeoastronomy*, edited by A.F. Aveni, pp 499. Cambridge University Press

Sofaer, A.

2007 The Primary Architecture of the Chacoan Culture: A Cosmological Expression. In *Architecture of Chaco Canyon, New Mexico,* edited by S. Lekson, pp. 225-254. University of Utah Press, Salt Lake City.

Sofaer, A., and R.M. Sinclair, R.M.

1987b Astronomical Markings at Three Sites on Fajada Butte. In *Astronomy and Ceremony in the Prehistoric Southwest*, edited by J. Carlson and W.J. Judge, pp. 43-70. Maxwell Museum of Anthropology, Anthropological. Papers 2, University of New Mexico, Albuquerque.

Sofaer, A., R.M. Sinclair, and L. Doggett

1982 Lunar Markings on Fajada Butte, Chaco Canyon, New Mexico. In *Archaeoastronomy in the New World,* edited by A.F. Aveni, pp.169-181. Cambridge University Press.

Sofaer, A., M.P. Marshall, and R.M. Sinclair

1989 The Great North Road: a Cosmographic Expression of the Chaco Culture of New Mexico. In *World Archaeoastronomy*, edited by A.F. Aveni, pp. 365-376. Cambridge University. Press.

Sofaer, A., R.M. Sinclair, and J.B. Donahue

1991 Solar and Lunar Orientations of the Major Architecture of the Chaco Culture of New Mexico. *Proceedings of the Colloquio Internazionale: Archeologia e Astronomia*, 137-150, edited by G. Romano and G. Traversari.

Sofaer, A., R.M. Sinclair, and R. Williams

1987a A regional pattern in the architecture of the Chaco Culture of New Mexico and its astronomical implications. *Bulletin of the American Astronomical Society* 19:1044.

Sofaer, A., R. Weiner, and W. Stone

2016 Inter-Site Alignments of Prehistoric Shrines in Chaco Canyon to the Major Lunar Standstill. Edited by E.F. Arias, L. Combrinck, P. Gabor, C. Hohenkerk, and P.K. Seidelmann, pp. 79-102. *The Science of Time*, Springer, New York City.

Sofaer, A., V. Zinser, and R.M. Sinclair

1979 A unique solar marking construct. *Science* 206:283-291.

Stein, J. R

1989 The Chaco roads-Clues to an ancient riddle? *El Palacio* 94:4-16.

Stein, J. R., and S.H. Lekson

1992 Anasazi Ritual Landscapes. In *Anasazi Regional Organization and the Chaco System*, edited by D.E. Doyel, pp. 87-100. Maxwell Museum of Anthropology Anthropological Papers 5, Albuquerque, New Mexico.

Stein, J.R., D. Ford, and R. Friedman

2003 Reconstructing Pueblo Bonito. In *Pueblo Bonito: Center of the Chacoan World*, edited by J.E. Neitzel, pp. 33-60. Smithsonian Books, Washington, DC.

Stein, J.R., R. Friedman, T. Blackhorse, and R. Loose

2007 Revisiting Downtown Chaco. In *The Architecture of Chaco Canyon New Mexico*, edited by S.H. Lekson, pp. 199-223. University of Utah Press, Salt Lake City.

Stubbs, S.

1950 Bird's Eve View of the Pueblos. University of Oklahoma Press, Norman.

Tankersley, K.B., N.P. Dunning, J. Thress, L.A. Owen, W.D. Huff, and others

2016 Evaluating soil salinity and water management in Chaco canyon, New Mexico. *Journal of Archaeological Science: Reports* 9:94–104.

Toll, H.W.

1985 Pottery Production, Public Architecture, and Chaco Anasazi System. PhD dissertation, Department of Anthropology, University of Colorado, Boulder.

Toll, H.W.

1991 Material Distributions and Exchange in the Chaco System. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by P. Crown and W.J. Judge, pp. 77-107. School of American Research, Santa Fe, New Mexico.

Toll, H.W.

2001 Making and breaking pots in the Chaco world. *American Antiquity* 66:56-78.

Toll, H.W., M.S. Toll, M.L. Newren, and W.B. Gillespie

1985 Experimental Corn Plots in Chaco Canyon. In *Environment and Subsistence of Chaco Canyon, New Mexico*, edited by F.J. Mathien, F.J., pp.79-133. Publications in Archaeology 18, Chaco Canyon Studies, National Park Service, Albuquerque, New Mexico.

Van Dyke, R.M., R.K. Bocinsky, T.C. Windes, and T.J. Robinson

2016 Great houses, shrines, and high places: Intervisibility in the Chacoan world. *American Antiquity* 81:205-230.

Van Dyke, R. M.

2007 *The Chaco Experience: Landscape and Ideology at the Center Place*. School of American Research Press, Santa Fe, New Mexico.

Van Dyke, R. M.

1999 The Chaco connection: Evaluating Bonito-style architecture in outlier communities. *Journal of Anthropological Anthropology*.18:471-506.

Van Dyke, R.M.

2002 The Chacoan great kiva in outlier communities: Investigating integrative spaces across the San Juan basin. *Kiva* 67:232-247.

Van Dyke, R.M.

2018 From enchantment to agencement: Archaeological engagements with pilgrimage. *Journal of Social Archaeology* 18:348-359.

Vivian R.G.

1974 Conservation and Diversion: Water-Control Systems in the Anasazi Southwest. In *Irrigation's Impact on Society*, edited by T.E. Downing and M. Gibson, pp. 95-112. Anthropological Papers of the University of Arizona 25, University of Arizona Press, Tucson.

Vivian R.G.

1990 *The Chacoan Prehistory of the San Juan Basin*. Academic Press, New York.

Vivian R.G.

2004 Puebloan Farmers of the Chacoan World. In Noble, D.G. (Ed.), In *Search of Chaco: New Approaches to an Archaeological Enigma*, edited by D.G. Noble, pp. 7-13. School of American Research Press, Santa Fe, New Mexico.

Vivian, R.G.

1972 *Prehistoric water conservation in Chaco Canyon*. Final Technical Report, National Science Foundation Grant No. GS-3100, Washington DC.

Vivian, R.G.

1980 Discovery and Description: Chacoan Road Field Studies 1963-1980. Chaco roads project, phase I, Appendix. A, pp.1-34.

Vivian, R.G.

1992 Chacoan Water Use and Managerial Decision Making. In *Anasazi Regional Organization and the Chaco System*, edited by D.E. Doyel, D.E, pp. 45-57. Anthropological Papers 5, Maxwell Museum of Anthropology, University of New Mexico, Albuquerque.

Weiner, R.S.

2018 Sociopolitical, ceremonial and economic aspects of gambling in ancient North America: A case study of Chaco Canyon. American Antiquity 83:34-53.

WGEW

2019. Walnut Gulch Experimental Watershed, Southwest Watershed Research Center, Tucson, Arizona. https://www.tucson.ars.ag.gov/swrc_site/research/wgew.

Wills, W.H.

2001 Ritual and mound formation during the Bonito phase in Chaco Canyon. *American Antiquity* 66:433-451.

Windes, T.C.

1987 *Investigations at the Pueblo Alto Complex, Chaco Canyon. Vol. II*. Publications in Archaeology 18F, Chaco Canyon Studies, National Park Service, Santa Fe, New Mexico.

Windes, T.C., M. Rachel. B.K. Anderson, and C.A. Ford

2000 Sunrise, Sunset, Sedimentism and Mobility in the Chaco East Community. In *Greathouse Communities Across the Chacoan Landscape*, edited by J. Kantner and N.M. Mahoney, pp. 39-59. Anthropological. Papers of the University of Arizona. 64, University of Arizona. Press, Tucson.

World Statistics

2012 Country Codes and Quick Population Facts. http://www.os-connect.com/pop/.

Supplementary Text 1. Studies Suggesting that Chaco Canyon was Agriculturally Productive

Supplementary Table 1, Watering schedule requiring a total of 50 cm over a 120 day period.

Supplementary Figure 1. Top. Course of Vivian canal in Chaco Canyon. Bottom. Elevational transect of the canal.

Figure captions:

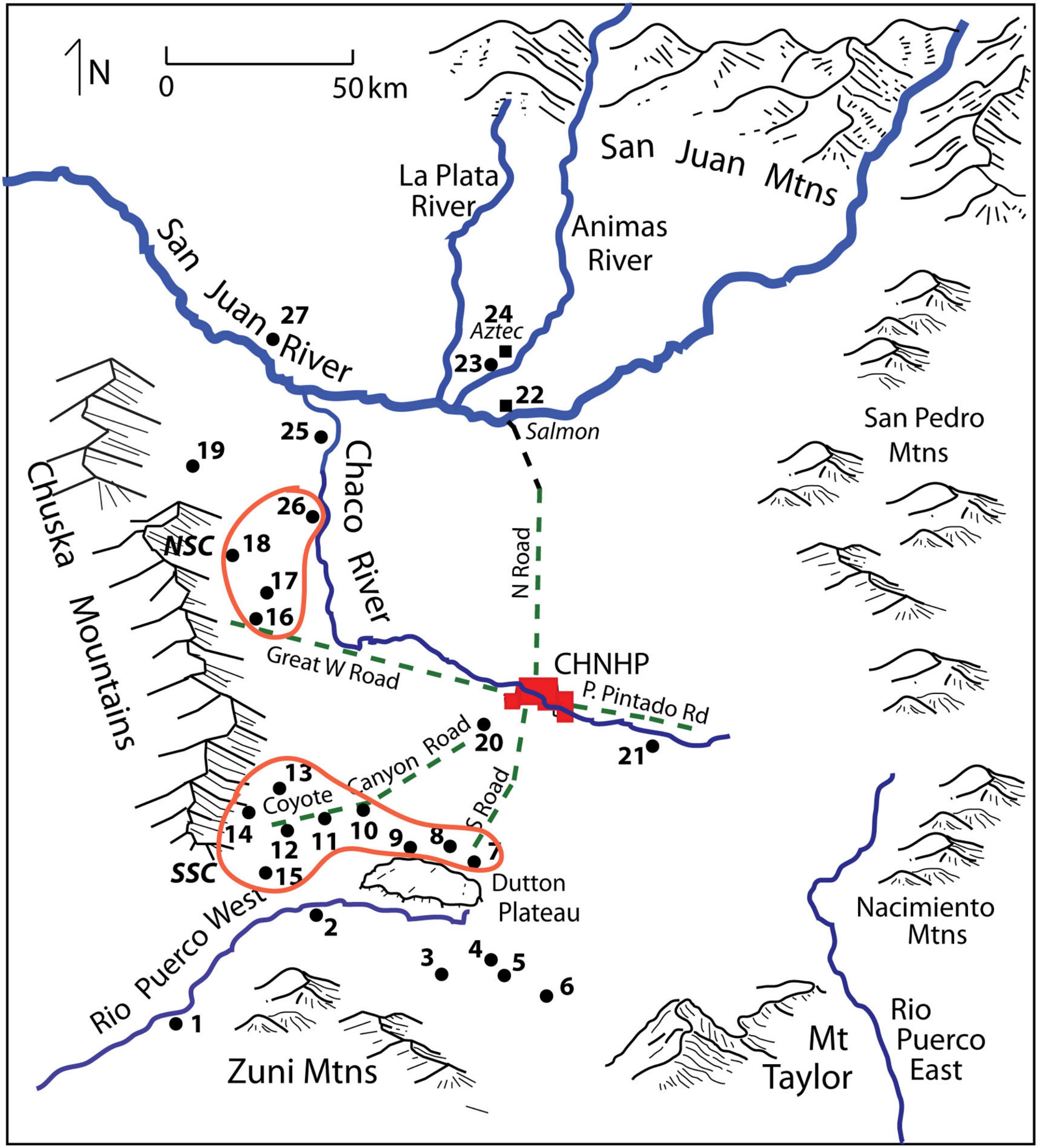
Figure 1. Schematic map of the San Juan Basin showing Chacoan ceremonial roads (dashed lines) and major outlying communities (numbered dots keyed to site list in Table 1). ***NSC*** is the Northern Super Community and ***SSC*** is the Southern Super Community. Figure 1 is a modification version of Figure 9.1 in Sofaer (2007).

Supplementary Figure 1. a. Google Earth map of the west end of Chaco Canyon with Vivian Canal shown by solid line. b. Elevational transect along hypothetical canal.

Tables:

Table 1. Large Great House Communities in the San Juan Basin.

Supplementary Table 1. Watering Schedule Requiring a total of 50 cm during a 120-day period.



N
0
50 km
San Juan Mtns
La Plata River
Animas River
San Juan River
27
24
Aztec
23
22
Salmon
25
19
Chaco River
Chuska Mountains
26
NSC
18
17
16
N Road
Great W Road
CHNHP
P. Pintado Rd
20
21
Canyon Road
13
Coyote
14
12
11
10
9
8
7
S Road
SSC
15
Dutton Plateau
2
Rio Puerco West
3
4
5
6
1
Zuni Mtns
Mt Taylor
Rio Puerco East
San Pedro Mtns
Nacimiento Mtns

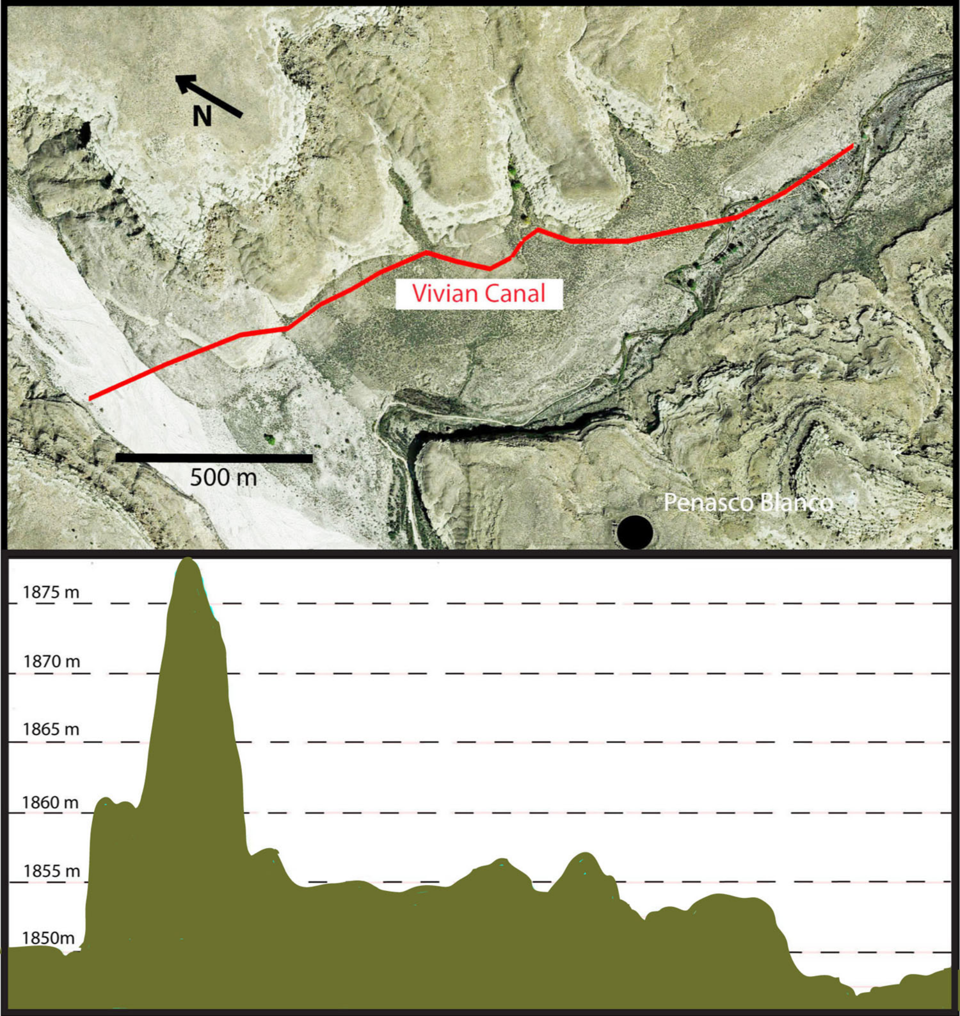

N
Vivian Canal
500 m
Penasco Blanco
1875 m
1870 m
1865 m
1860 m
1855 m
1850m

Figure captions:

Figure 1. Schematic map of the San Juan Basin showing Chacoan ceremonial roads (dashed lines) and major outlying communities (numbered dots keyed to site list in Table 1). ***NSC*** is the Northern Super Community and ***SSC*** is the Southern Super Community. Figure 1 is a modification version of Figure 9.1 in Sofaer (2007).

Supplementary Figure 1. a. Google Earth map of the west end of Chaco Canyon with Vivian Canal shown by solid line. b. Elevational transect along hypothetical canal.

Supplementary Table 1. Watering Schedule

Requiring a Total of 50 cm during a 120-day Period

days	cm	cm/day
20	2.4	0.12
10	1.8	0.18
10	3.0	0.30
10	4.0	0.40
10	4.2	0.42
10	5.0	0.50
30	20.0	0.67
10	5.0	0.50
10	4.6	0.46

Note : Data from http://extension.missouri.edu/scott/documents/Ag/Irrigation/Corn-Irrigation-and-Water-Use.pdf (2019) adjusted for 50 cm water input

Table 1. Large Great House Communities in the San Juan Basin

These sites are shown on Fig. 1

Site No.	Site name	Site No.	Site name
1	Kin Hochoi	15	Tolakai
2	Church Rock	16	Skunk Springs
3	Tse Bikin Tsoh	17	Newcomb
4	Casa Mero	18	Tocito
5	Andrews	19	Mitten rock
6	Haystack	20	Kin Bineola
7	Kin ya'a	21	Pueblo Pintado
8	Muddy Water	22	Salmon
9	Dalton Pass	23	Kello Blancett
10	Standing Rock	24	Aztec
11	Peach Springs	25	Hogback
12	Grey Ridge	26	Sanostee
13	Red Willow	27	El Malpais
14	Figueredo		

Supplementary Text 1. Studies Suggesting that Chaco Canyon was Agriculturally Productive

The origin of the concept of Chaco as a place of abundant agriculture

The Southwest archaeologist Gordon Vivian worked in Chaco Canyon for several decades until the late 1950s (Richert 1967). While there he discovered evidence of what he believed were prehistoric water-control systems. Vivian interpreted linearities he found on aerial photos as canals. He never fully published his observations but his son Gwinn continued in his father's footsteps over time focusing much of his research on irrigation features and their theoretical ability to increase the agricultural productivity of the Canyon (e.g., Vivian 1972, 1974, 1990, 1992, 2004).

In 1929 Charles Lindbergh photographed a single gridded feature near Chetro Ketl. Vivian (1990) suggested that this feature was a gridded garden and that runoff from 28 side-valley fans along the north side of the Canyon was channeled to such features via ditch and headgate systems. Unfortunately, there is no consensus on the nature of the gridded field and other gridded features have not been found.

With respect to irrigation canals, (Vivian 1980) excavated one of the Canyon's canals between Pueblo Alto and Chetro Ketl and discovered that the canal was actually a road surrounded by masonry walls. In addition, a number of other proposed canals were later found to be segments of the Chacoan road network (Lagasse et al. 1984).

With respect to observations of archaeological impoundments and irrigation features found in the Canyon, Judd (1954) indicated they were similar in every respect to those created by the historical Navajo people living in the Canyon. This suggests that most if not all irrigation features in the Canyon may have been created by the Navajo.

The next five sections (*3.2-3.6*) of this paper are devoted to an evaluation of recent studies that suggest Chaco Canyon was an agriculturally productive environment.

A recent study that purports to have substantiated the presence of old canals

Confusion as to the existence of canals persists. In a recent paper, Scarborough et al. (2018) claim to have documented an agricultural canal system on the north side of the Canyon, running between Chaco Wash and North Mesa. They excavated two pits within a 1.7 km-long geomorphic feature mapped by Gordon Vivian many years ago and which Vivian thought carried water from Chaco Wash to the west end of the Canyon. In addition, they employed LiDAR images of the west end of the Canyon to posit the existence of two canals; one emanating from Escavada Wash and the other from Chaco Wash. The two postulated canals parallel each other for ~200 m along the valley floor.

In terms of the stratigraphic section revealed by the two pits and depicted in Figure 4 of Scarborough et al. (2018), the presence of silty clay does not necessarily imply a canal. Silty clay can also be deposited via a fluvial system composed of a master stream (Chaco Wash) flowing generally west and it could also have been deposited via side-canyon alluvial fans. One potential problem with the study by Scarborough et al. (2018) is the assumption that the direction of sediment transport was perpendicular to their trench wall. A north-south cross section of a southward-trending meter-wide natural channel emanating from a side canyon could also produce the stratigraphy depicted in their Figure 4.

The OSL and ^{14}C dates obtained by Scarborough et al. (2018) on the two pits can be interpreted to indicate two episodes of sediment deposition separated by approximately 900 yr. In the following, ^{14}C dates have been expressed as the midpoint of their estimated age ranges ± half the age ranges for comparison with OSL dates. The sedimentary package illustrated in Figure 4 of Scarborough et al. (2018) consists of 0.5 m of near-modern (1805 ± 145 CE) sediment overlying 0.5 m of sediment deposited during an apparently brief time interval at ~900 ± 100 CE. Unit K, the bottom most unit in the section, and unit D, at the top of the lower 0.5-m section, have identical OSL ages (900 ± 100 CE), whereas most samples in the upper half of the stratigraphic sequence beginning with Units C-1, C-2, and C-3 have identical ^{14}C ages of 1805 ± 145 CE. The differences in ages of the upper and lower half of the section indicate a depositional hiatus between 900 ± 100 and 1805 ± 145 CE, which spans nearly the entire Anasazi occupation of Chaco Canyon.

Within the upper half of the relatively modern sediments there is one chunk of anomalously old sediment (Unit C-4) that has OSL and ^{14}C dates of, respectively, 1000 ± 100 CE and 1075 ± 75 CE, and within the lower half of the sedimentary sequence there is also an anomalously old ^{14}C date on Unit D of 330 ± 70 CE. This suggests the presence of reworked older material. The presence of allochthonous sediment chunks, which are neither bed nor suspended load, indicates a depositional environment other than a canal. A canal's sediment should become younger the higher the position in the sediment column. Instead, the sediments in the pits shown in Figure 4 of Scarborough et al. (2018) were probably deposited episodically from a side canyon where from time to time, sediments of different ages were eroded.

The data, therefore, indicate that the upper half of sediment was deposited after the incision of Chaco Wash and could not have been deposited via a canal leading from the Wash because Chaco Wash began to incise between 1849 and 1877 (Simpson 1852; Jackson 1878). Most of the bottom half of the sedimentary package was deposited prior to Chaco's rapid expansion between 1050-1130 C.E. Therefore, the ages of the stratigraphic units cannot be interpreted to indicate that an irrigation canal was in place for any great length of time and certainly not during the rapid expansion of Chaco.

The Vivian canal cross section depicted in Figure 5 of Scarborough et al. (2018) appears to indicate a very shallow ditch (≤0.5 m) that could not have held much water. Flooding of Chaco Wash would have overwhelmed the shallow ditch's capacity leading to massive erosion of its southern edge unless the ditch system had been bermed and rock armored (Benson and Grimstead 2019), and such armoring is not present. In addition, there is no evidence of ditch maintenance in the stratigraphic section presented by Scarborough et al. (2018); i.e., berms resulting from semi-continuous removal of sediment from the canal should be present but are not. The use of the term "canal clays" in the caption of their Figure 5 is not warranted. The deposits are silty clays and it is incorrect to telegraph one's interpretation of a sedimentary fabric. The same problem occurs with their description of a sand dune in an earlier section of the paper that they call a "dune dam".

It remains unclear how the canal could have been used for irrigation. Rock armored head gates positioned along the southern edge of the canal would have been employed if flood water was diverted to fields on the adjacent valley bottom. No such structures have been noted. The "Vivian" canal shown in Figure 1 of Scarborough et al. (2018)

appears to cross the 1854-m and 1856-m contour lines at several points suggesting the feature is neither level nor does it have a consistent dip to the west. Such a variable level is inconsistent with the presence of a canal. The canal is not visible on Google Earth, yet prehistoric canals west of Kin Bineola are quite visible. In addition, LiDAR data collected by the National Center for Airborne Laser Mapping (Dorshow 2019) and employed by Scarborough et al. (2018) does not indicate a continuous set of landforms associated with the presence of a ditch or canal.

In order to determine the slope of the hypothetical Vivian canal, its position was located on Google Earth (Supplementary Figure 1a) and a down-Canyon elevational path created (Supplementary Figure 1b). The elevational profile of the canal clearly indicates that water would have had to flow uphill from Chaco Wash to reach the west end of the Canyon. The two proposed canals at the west end of the Canyon are also not evident in Google Earth and LiDAR images shown in Figure 7 of the Scarborough et al. (2018) paper do not indicate their presence.

Perhaps the part of the feature that Scarborough et al. (2018) interpret as a canal is actually an abandoned road that predates the initial 1933 Civil Conservation Core occupation of the Canyon. In the early 1900s, the town of Putnam with a post office and trading post was established in the Canyon core. The Canyon also became the headquarters of the Wetherill/Hyde trading and ranching operations in 1901, and in 1909 the Eastern Navajo Agency was established in the Canyon (see, e.g., Brugge 1980). In addition, numerous archaeological expeditions occupied the Canyon, including the National Geographic Smithsonian expedition in the 1920s. These groups needed a road to travel to Farmington, New Mexico, and such roads would have been abandoned from time to time as their conditions deteriorated due to flooding or dune formation [see, e.g., the Bauer and Reeside (1921) road map depicted in Figure 2 of Brugge (1980), which shows two roads leaving the west end of the Canyon and the road depicted in Figure 1 of Judd (1954).

A **geospatial simulation of the agricultural productivity of Chaco Canyon**

Dorshow (2012) recently employed a model dealing with geospatial analysis of surficial hydrology and geomorphology of the Chaco Canyon area in an attempt to show how these factors relate to Chaco's agricultural productivity. The overall problem with the approach of Dorshow is that it is not processed based (i.e., it does not accurately duplicate processes that occur in natural systems and that govern maize productivity). Models dealing with natural phenomena such as surface-water runoff must be calibrated and validated in order demonstrate their ability to simulate such processes, activities that were not performed by Dorshow.

Dorshow (2012) argued that the natural agricultural suitability of soils is considered to be very high in coarse- and fine-loam soils, yet no data on water retention or organic carbon and nitrogen concentrations of those soils were presented. Treatment of water availability by Dorshow (2012) is rather superficial. Basically, he considers a scenario where the annual-average amount of precipitation is instantaneously released to the landscape and a certain fraction of that water is allowed to runoff in the form of sheetwash. In actuality, snowmelt runoff and precipitation occur in discrete events and any model of runoff resulting from such events must consider the frequency, magnitude, and timing of such events as well as the rate of infiltration. In general, issues affecting water availability in the model grossly overestimate the natural agricultural productivity of the landscape studied.

The unstated implication of Dorshow's (2012) modeling effort is that dryland farming can be done in areas within and surrounding Chaco Canyon, including the slick rock mesas that border the Canyon. In order to supply water to such areas he suggested that pot watering from the Escavada or Chaco washes was feasible but did not offer labor costs for such watering. Previous attempts at pot watering of maize in in the Canyon have proven unsuccessful. Experimental maize test plots in the 1970s were conducted in several areas of Chaco Canyon and maintained over a three-year period. The fields were hand watered, yet beans and gourds did so poorly in the first two years that only maize was planted in the last year. One plot was located within the Chetro Ketl field where the "gridded garden" existed. There only 43% of the maize seeds germinated and, on average, the plants survived only 79 days and no ears formed. Two other plots, one near Weritos Rincon and the other near Penasco Blanco, produced some cobs but the plants were <60 cm in height with few kernels present. The conclusion of the study was that "Even in proven locations…. farming is Chaco is risky and regular failures are a good possibility on a regular basis" (Toll et al. 1985). Pits would have to have been dug into the washes in order to obtain water held in their porous sediments. As most of the Canyon area is situated far from intermittent surface-water systems, carrying water to distant fields would have consumed a great amount of time.

In the following, it is assumed that in order to feed a family of five, five acres must be planted to produce 25 bushels of maize. Each acre contains 440 hills of maize separated by 3 m, and the minimum amount of water needed to produce a successful crop is 50 cm (Missouri Extension 2019). It is assumed that the watering diameter is 0.5 m for each hill, the rooting depth is 1 m, and the soil is a silt loam with a porosity of 50%.

Let A = area, V= volume, y = rooting depth, r = radius, ϕ = porosity, d = diameter, H = hill number, ac = acres, gal = gallons, hr = hours, D = days, T = trips, lb = pounds, and bu = bushels.

The volume of water added to 2200 hills reaching a rooting depth of 1 m is given by:

$$V = \pi r^2 \bullet \phi \bullet y \bullet 2200 \therefore V = 3.142 \bullet (0.25)^2 \bullet 0.5 \bullet 1.0 \bullet 2200 = 216 \text{ m}^3$$

$$216 \text{ m}^3 = 57{,}061 \text{ gal} = 476{,}197 \text{ lb}$$

Assume a person can carry 40 lb of water each trip T.

$$\text{Then } T = 476{,}197 \div 40 = 11{,}904 \text{ trips}$$

For a 120-day growing season, the average number of trips per day is given by

$$T/D = 11{,}904 \div 120 = 99 \text{ trips}$$

And, If each round trip takes 0.5 hr, then

$$hr/D = T/D \bullet hr/T = 99 \bullet 0.5 \approx 50 \text{ hr}$$

Obviously, a family of five cannot spend 50 hours per day hand watering five acres of maize, especially if their children are young. The situation becomes even worse during silking and grain fill (days 70-100 when water demand increases to 0.67 cm/D; Supplementary Table 1), because time spent watering becomes 87 hr/D.

If in the future, it becomes important to understand the surface-water hydrology of the Chacoan landscape and its relationship to maize productivity, a processed-based surface-water runoff model such as PRMS should be employed (Markstrom, 2019). Such a model should be applied to typical landforms found in Chaco Canyon such as side-valley alluvial fans, which should be instrumented and monitored in the manner of the Walnut Gulch Experimental Watershed in southern Arizona (WGEW, 2019). Within the modeled area(s), experimental agricultural plots should be created and coupled to a variety of irrigation methodologies in order to understand what methods work well and how much maize could be raised in the Canyon if they were employed.

Studies of Chaco soils

Early studies tended to suggest that Chaco soils were not conducive to farming. Judd (1954, 1964) suggested that because of the high sodium content and low alkalinity of valley-floor soils Anasazi farmers would have preferred side-valley fans for farming. Bradfield (1971) collected a single soil sample from the valley floor of the Canyon and found that it was much more saline than 15 samples collected from Hopi fields.

Two recent studies (McCool et al. 2018; Tankersley et al, 2016) have attempted to support Vivian's concept of an agriculturally productive Canyon by arguing that the Canyon's soils are not highly saline but fertile, with Tankersley et al. (2016:102) concluding that "Rather than viewing Chaco Canyon as an arid environmental wasteland, Ancestral Puebloan innovations in water management created an agricultural oasis".

Tankersley et al. (2016) argued that the salinity of Chaco's soil waters derived from sulfate-bearing minerals and that the salinity associated with dissolved sulfate enhances the growth of maize. However, Benson (2017) pointed out that (1) increased salinity associated with sulfate-rich water was just as detrimental to plants as salinity derived from sodium bicarbonate or sodium chloride rich soil water, (2) that farmers add sulfur to their soils to reduce the aluminum toxicity of acid soils whereas Chaco soils are alkaline and do not require added sulfur, and (3) that sodium and bicarbonate chemical species and not sulfate species dominate Chaco Canyon's soil water.

In his reply to Tankersley et al. (2016), Benson (2017) attempted to characterize the salinity of Chaco side-valley fan and valley-floor soils using lab measurements of soil conductivity. From these measurements together with an estimate of the field capacity of Chaco soils, Benson (2017) calculated the actual soil-water salinity in contact with the roots of hypothetical maize plants growing in those soils. He then used the calculated salinity (conductivity) data to estimate the relative yield of maize grown in those soils and concluded that most Canyon valley floor soils were too saline to support the growth of maize. However, McCool et al. (2018) correctly pointed out the relative yields of maize and beans were a function of the conductivities of lab-based saturated soil-water extracts (Ayers, 1977) not of calculated actual values.

Unfortunately, this does not alleviate concerns regarding the salinity of Canyon valley floor soils with respect to the growth of maize. Benson and Grimstead (2019) modeled the area of unincised valley floor wetted by spring floods of the Chaco River using modern discharge data. Given the small amount of water infiltrating the valley floor via winter precipitation (9.8 cm), it is likely that Canyon farmers would have planted within the area wetted by spring floods in order to ensure maize germination. Benson and Grimstead (2019) found that most historic spring flows never exceed a 40-m width, indicating that <100 acres centered on the axis of the valley bottom could be farmed. Specifically, Chaco Canyon valley farming would have been confined to small areas of the valley floor 92% of the time. Soil conductivities along this strip of land have yet to be measured and it may prove impossible to do so if the present incised channel of Chaco Wash is found to lie along the former valley-floor axis. In any case, 85% of the time summer floods would have severely damaged or destroyed spring plantings, not leaving sufficient time to replant and harvest prior to autumn's first freeze day.

The Chaco Halo as a possible source of Chaco's food

Doyel et al. (1984) suggested that settlements surrounding Chaco Canyon may have supplemented the amount of agricultural product available to Canyon. Their test case was the relatively small Bis sa'ani community located 15 km north of Chaco Canyon on the floodplain of the Escavada Wash. The overall area considered in the study was an oval 130 km^2 in area, centered on Pueblo Bonito, and containing several villages mostly situated along drainages of the Escavada, Chaco, and Fajada washes. They termed the oval-shaped region the "Chaco Halo".

With respect to the Chaco Halo, Doyel et al. (1984) concluded that Bis sa'ani, the only community studied in detail, was not capable of producing a food surplus. The other seemingly large settlements that did not possess Bonito-style architecture may indeed have been farming communities; however, there are no studies to date that indicate these areas were sufficiently productive to provide surplus foodstuffs to the Canyon.

Lake Chaco

Force et al. (2002) and Force (2004) proposed that a set of sand dunes near the confluence of the Chaco and Escavada washes damned the Chaco River sometime between 900-1150 CE forming a small lake. This impoundment was thought to have some importance as a potential water supply for farming.

However, Love et al. (2011) demonstrated that this lake never existed. The volume of dune sand would have had to double to reach the height of the proposed upstream lake beds described by Force et al. (2002), and even if the dune had been higher in the past, breaching of it would proceed catastrophically given the magnitudes of modern Chaco Wash floods. The supposed lake-bed sediments most likely represent levees or overbank deposits. In addition, ^{14}C dates on charcoal from the supposed lake beds predate 900 CE (Love, et al. 2011) demonstrating that the hypothetical lake sediment predated the expansion of Chaco that began at 1050 CE.

The papers discussed in this section have attempted to demonstrate that Chaco was agriculturally productive. However, none of them have demonstrated that farming in Chaco Canyon could sustain a population of 2000 residents during the period 1050-1130 CE.

Note: References in the Supplementary Text have been included in the master References Cited section of the paper.