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Agriculture and community in Chaco Canyon: Revisiting Pueblo Alto

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ABSTRACT

The Bonito Phase (ca. AD 860–1140) in Chaco Canyon is widely recognized as one of the primary sources of information about emergent social complexity in prehispanic North America. Large masonry buildings called "great houses," such as Pueblo Bonito, are iconic symbols of the rapid rise of a powerful society based on the ability to harness labor to prolonged construction projects. It is clear that the political forces at work during the Bonito Phase had an agricultural foundation, presumably in the financing of construction through food surpluses, but the actual nature of farming in Chaco is surprisingly opaque to archaeologists. Indeed, many researchers have concluded that farming in Chaco Canyon was too constrained by poor soils to have supported the dynamic developments associated with the massive stone structures and extensive trade systems of the Bonito Phase. The popular perspective that Chaco was mysterious or enigmatic is largely a response to this view of the canyon as agriculturally marginal. In this study we argue that a predictive model of potential agricultural productivity that includes other portions of the canyon besides the floodplain indicates that Chaco was not marginal for farming. The results of this analysis suggest that great house communities may have been sited to control local production zones and that some great houses may have been linked to others in order to manage multiple agricultural areas.

1. Introduction

The Chaco world of masonry great houses, cosmography, and ritual had an agrarian soul. However much archaeologists may dispute the social or political nature of that world, it is a simple fact that the people who built the great houses of Chaco Canyon (Fig. 1) during the Bonito Phase (ca. AD 860–1140; see Windes and Ford, 1996) were farmers and their success as farmers is the key to understanding their society. By the time the first building stones were set in place at Pueblo Bonito (Fig. 2) around AD 860, farming had been important to indigenous societies throughout the American Southwest for more than three millennia (Huber and Van West, 2005; Merrill et al., 2009; Hall, 2010). Farming is the only conceivable source for the economic surplus required to fund the construction of Chaco great houses and is thus inherently part of the explanation for the emergent social complexity that occurred there. Yet we know surprisingly very little about the relationship between food production and social life, which was presumably the backbone of Chaco's political economy.

The dominant archaeological narrative about farming and the construction of great houses follows a fairly vague historical trajectory popularized by Jared Diamond (2005) in which an initial period of population growth fueled by food surplus (mainly maize) created an economic boom that allowed ambitious individuals to convert unanticipated agricultural gains into political power. Competition between the newly powerful drove great house construction and intensification of production, thereby straining local carrying capacity and depleting natural local resources, which put the canyon's population on a pathway to economic catastrophe and diaspora when confronted with serve drought in the 12th century AD (see Sebastian, 2004; Fagan, 2005). This is an imminently satisfying scenario from which some scholars have been quick to draw a cautionary warning for modern society (Stuart, 2000; Diamond, 2005). However, the fact is that the agricultural component in the narrative of Chaco's rise and fall is simply inferred from either the historical record of canyon occupation or from reconstructed weather patterns, rather than derived from actual archaeological studies of farming in Chaco Canyon. Many researchers *assume* that food surpluses catalyzed the rapid rate of building construction evident between AD 1020 and 1080. Most Chaco scholars *assume* that the apparent collapse of Chaco society in the 12th century was set in motion by the decline or failure of agricultural systems. Neither of these assumptions about the role of food production has been independently verified (see Vivian et al., 2006).

Although archaeologists often refer to "irrigation works" or "agricultural intensification" as facets of Chacoan society, the evidence for irrigation is limited to directed runoff from side tributaries into gridded fields during episodic rainfall events, the dating of individual water control features is uncertain, and no researcher has presented any direct data demonstrating

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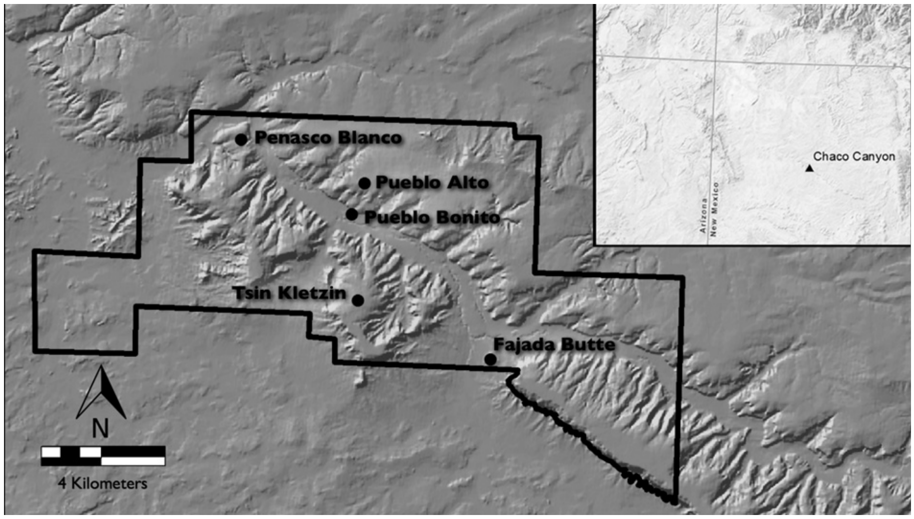

Fig. 1. Chaco Culture National Historic Park, New Mexico. Key places referenced in the text are highlighted.

Fig. 2. Pueblo Bonito facing south. Estimated number of rooms exceeds 600. Occupation span is ca. AD 860 to 1200 (plus), with three major construction periods associated with masonry styles (Early: ca. AD 860–940; Classic: ca. AD 1040–1100; Late: ca. AD 1100–1140) following Windes and Ford (1996).

intensification of food production (see Vivian, 1990; Earle, 2001; Sebastian, 2004; Vivian et al., 2006). Even some of the oft-cited evidence is unclear. For example, the only agricultural field in Chaco that has been excavated (partly) is just east of the Chetro Ketl great house and appears to post-date most of the Bonito Phase (Loose and Lyons, 1976; Force et al., 2002); some researchers argue that it was not even a field (Stein et al., 2007, p. 211). No other fields have been conclusively identified by excavation, although at least several were surely associated with known headgates (Vivian, 1990). An engineering study of an excavated head gate associated with a small feeder canal concluded that tributary runoff events were too massive to have been successfully diverted into either the canal or the gate structure and therefore suggested that such field systems were fed by local areas rather than tributary watersheds (Lagasse et al., 1984, p. 202). In her synthesis of Chaco research trends, Mills (2002, p. 83) observed that "…reconstructions of subsistence production that combine information on soils, storm patterns, crop types, yearly rainfall have yet to be conducted for the central canyon, much less Chaco's outlier communities."

In the absence of relevant archaeological data linking agriculture to historical dynamics (as opposed to evidence for cultivated plants, which is abundant), researchers have mainly relied on general observations that the north side of the canyon is better suited for runoff agriculture than the south side (Judge et al., 1981; Vivian, 1990). Thus, the presence of six great houses on the north side of the canyon (versus three on mesa tops) is attributed to higher farming potential associated with larger runoff events. Whether this hypothesis is correct is unknown because there has been no opportunity to connect settlement or demographic patterns over time to specific agricultural production measures.

While there is no doubt among specialists that crop cultivation was possible in Chaco in the past, a current influential perspective has emerged that creates huge explanatory complications for nearly all political models based on successful and predictable farming. According to several researchers, Chaco Canyon does not have enough arable land of sufficient agricultural quality to support even a small residential population (Schelberg, 1982, 1984; Benson et al., 2003; Benson et al., 2008; Benson, 2011; consider also Johnson, 1989). Recent descriptions of Chaco during the Bonito Phase as an "enigma" owe much to the dissonance created by images of a powerful political center handicapped by an inadequate agricultural base (Noble, 2004).

But if farming in Chaco was only marginal, where did the productive surplus for supporting the labor required to construct great houses come from? Currently the answer is food was imported from "outlier" communities in the surrounding San Juan Basin. Although the mechanisms for moving surplus from elsewhere into the canyon are unknown, researchers generally feel that such transfers were possible and probably the only way to explain the discrepancy between the amount of construction (which can be considered a proxy for energy investment) in Chaco and the hypothesized impoverished agricultural base (e.g., Fagan, 2005). Efforts to identify source areas for imported maize through strontium analysis have suggested some cobs found in Chaco may have originated in the Chuska Valley 40 km to the west or the San Juan River system equally distant to the north (Benson et al., 2008).

Unfortunately, while chemical sourcing studies for Chaco maize have been methodologically groundbreaking, the results are ambiguous. So far a total of 37desiccated maize cobs from canyon sites has been analyzed by Benson and associates (Benson et al., 2003; Benson et al., 2009), building on experimental studies by

Cordell et al. (2001). All but one of these cobs are assigned to source areas outside Chaco Canyon, some up to 75 km away (Benson et al., 2009, p. 403). But according to Cordell and colleagues (2008) these assignments are inconclusive because soil and water samples used to establish source areas within a geologically complex region of more than 25,000 sq km have been collected unsystematically, leaving vast areas unsampled (especially close to the canyon), including the buried land surfaces that were likely field locations. In at least one case, a published study of a "pre-Columbian" maize field argued to represent a distant maize source for Chaco was actually an historic Navajo plot (Friedman et al., 2003). Additionally, 24 cobs dating to the 12th century and interpreted as imports from the San Juan River valley 75 km north of Chaco could not have contributed to great house construction efforts in the 11th century during the primary period of great house construction (another six cobs were historic in age; see Benson et al., 2009).

The uncertainty about the nature of Bonito Phase farming (possibly productive, possibly not) has an important connection to the pervasive idea that great houses were built primarily as expressions of religious or political power, collectively forming cosmographic "sacred" or "ritual" landscapes comprised of inter-connected communities centered on Chaco (Fowler and Stein, 1992; Stein and Lekson, 1992; Marshall, 1997; Renfrew, 2004). Despite comparisons to monumental Neolithic structures like Stonehenge, none of these seminal cosmographic models makes any mention of agriculture in the social life of great house communities, apparently treating food production as an unrelated or independent background constant. In fact, there is hardly any substantive concern with farming in most recent synthetic studies of Chaco, regardless of their analytical focus (e.g., Kantner and Mahoney, 2000; Fagan, 2005; Lekson, 2006, 2007, 2009; Van Dyke, 2007).

Yet among historical southwestern indigenous peoples, agriculture is the foundation of social life, religious belief, ritual performance and symbolism (see Parsons, 1939; Ortiz, 1969), and there is evidence that Pueblo elites gain access to ritual positions of power through the ability to generate agricultural surplus that underwrites participation in events (Ford, 1972; Levy, 1992). It is therefore confusing that models of sacred landscapes, which can be fairly described as the prevailing archaeological paradigm about Chaco, express little concern with agriculture, while at the same time some researchers propose that the center of this ritual world lacked the economic means to provision itself and others argue that most outlying communities could not generate surpluses for export (Mahoney, 2000; Durand and Durand, 2000).

In this study we argue that local agricultural production in Chaco was more integral to great house communities than recognized in current conceptualizations of ritual landscapes consisting of buildings constructed primarily as cosmography. We suggest that generic cosmological interpretations of great house function unnecessarily marginalize the role of local economies and therefore overlook a critical aspect of the "lived" landscape that we need to understand to fully appreciate the socioeconomic developments associated with great houses. The provenance of this diminished agricultural perspective can be traced directly to the excavation and interpretation of Pueblo Alto in the 1970s (Lekson et al., 1988) and therefore we use Pueblo Alto as an example of how we might begin reinvigorating economic models of the Boni-

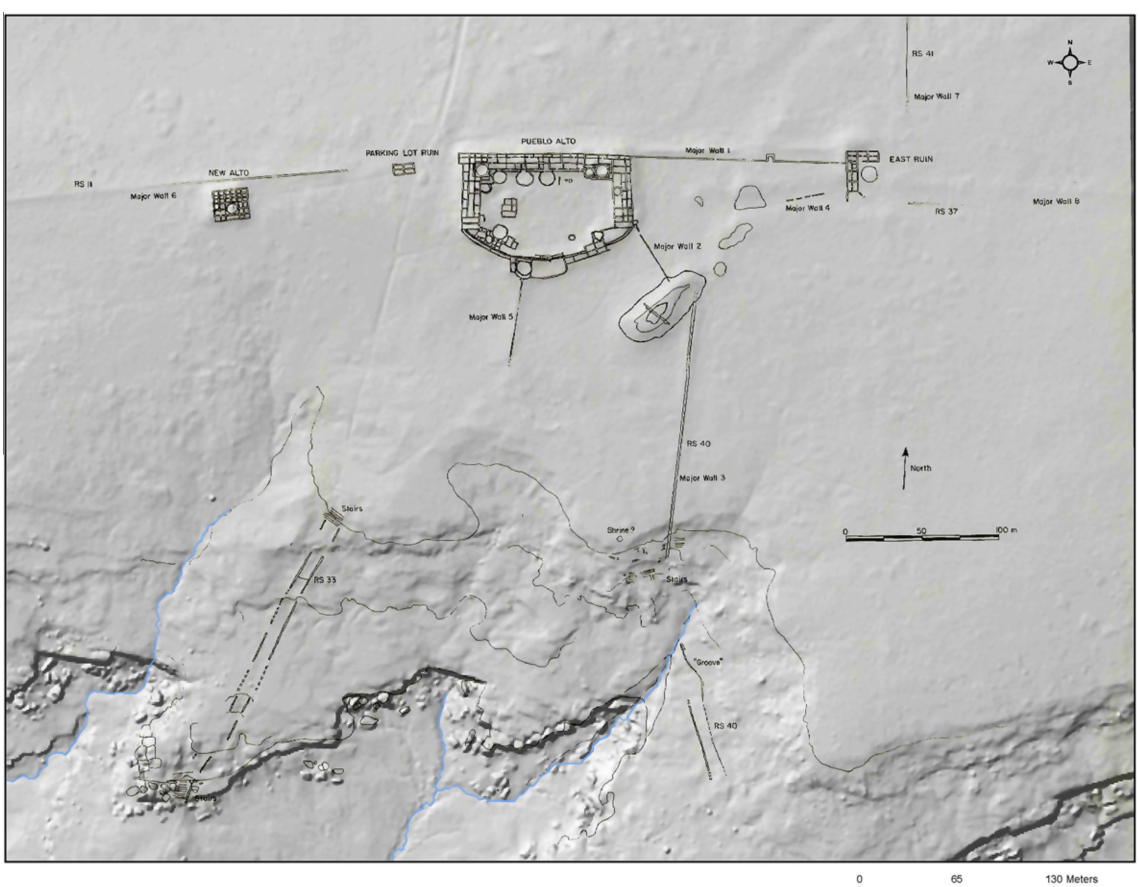

Fig. 3. The Pueblo Alto community complex defined by Windes (1987) shown superimposed on an elevation model derived from LiDAR data. Blue lines indicate drainage patterns. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to Phase by focusing more closely on food production in the canyon.

2. The pueblo alto community

2.1. Archaeological context

Pueblo Alto is a Classic style great house (Fig. 3) constructed on the mesa above Pueblo Bonito between AD 1020 and 1060, with occupation and remodeling occurring into the 12th century AD. The site was partially excavated in the 1970s, the only great house excavation in more than 50 years and therefore a primary data source for the Bonito Phase. Pueblo Alto is particularly interesting to us because Windes (1987, p. 30) concluded that Alto's "placement emphasizes a topographic setting rather than a concern with critical environmental advantages," following his argument that the mesa top was adverse to agriculture "except, perhaps, during very wet years." In other words, Pueblo Alto is conventionally seen as unlikely to exhibit a positive relationship to potential agricultural production.

Pueblo Alto is one of the largest canyon great houses in area (8.0 hec) but is relatively small in terms of rooms (133), has only one story and lacks a great kiva (Windes, 1987). The elevated aspect of the building provides extended views of the topography outside the canyon (although the canyon floor and most other great houses are not visible). A unique web of constructed linear features interpreted as "roads" surrounds the great house and there are several smaller residential buildings in the immediate vicinity, as well as at least three extramural plazas defined by low masonry walls and a large earthen mound (or midden) outside the southeast corner (Fig. 4). According to Windes (1987, p. 6; 1991), the high density of roads around Pueblo Alto indicates that it was the focal point of a community "complex" integrally linked to the great houses in the canyon immediately below, as well as to distant great houses beyond Chaco to the north. The Alto community defined by Windes contains two McElmo style buildings (New Alto and Rabbit Ruin) built in the 12th century which indicate either long-term continuity and growth or a reoccupation following the possible abandonment of Pueblo Alto in the late 11th century (Wills, 2009).

Socioeconomic interpretations of the Pueblo Alto community based on excavations in the 1970s emphasize its topographic position and the density and pronounced visibility of nearby roads as evidence that the great house had a mainly communicative role controlling physical access into Chaco from the north (a gateway community) and/or as a node in a system of signaling stations conveying information through fires or reflected light (Windes, 1987; Lekson et al., 1988). A significant part of this control function involved the performance of rituals by non-residents associated with an inferred destruction of large numbers of ceramic vessels (Toll, 1985). The perception of the Pueblo Alto community as a rather exotic place largely disconnected from the daily agrarian grind of raising crops in a challenging environment is expressed in Renfrew's (2004) characterization of Chaco during the Bonito phase as a "center of high devotional expression," drawing religious pilgrims who travelled the roads to a spiritual center place; Pueblo Alto was the literally the highest among the high (also Van Dyke, 2007).

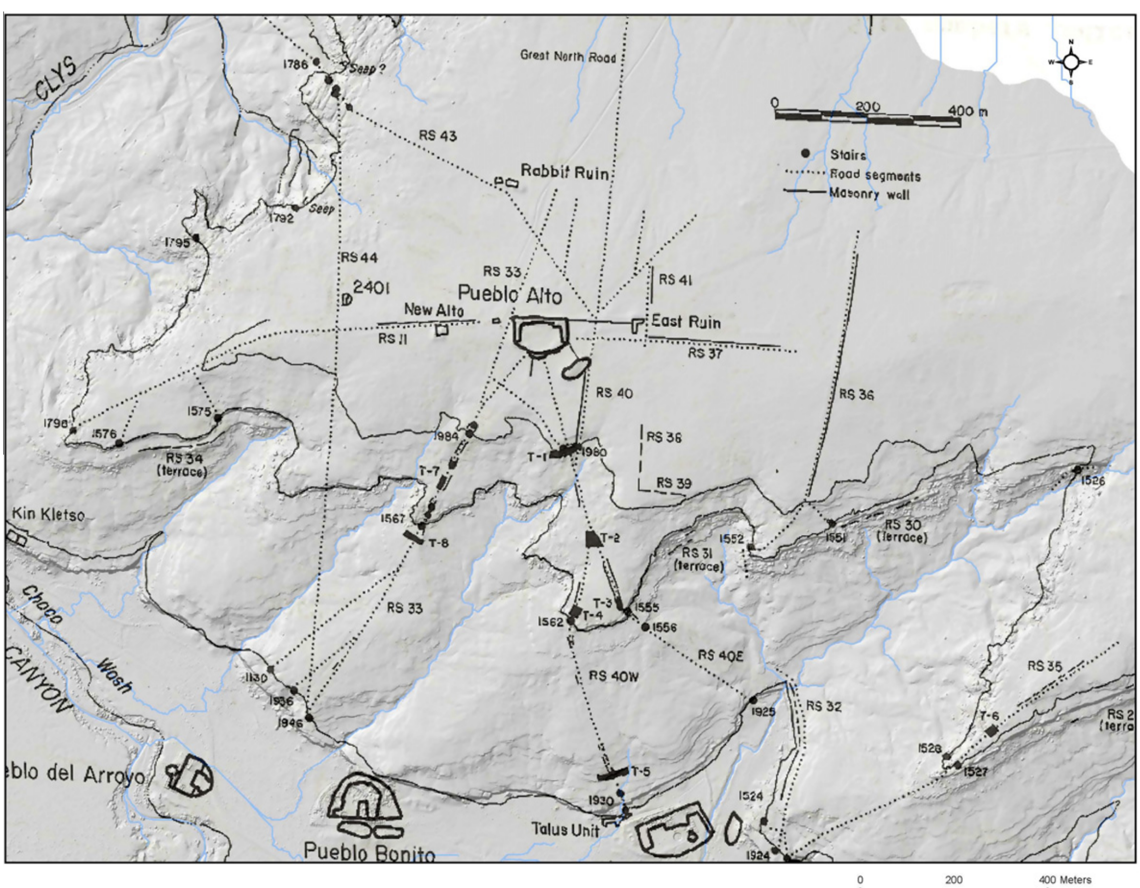

Fig. 4. The larger Pueblo Alto community complex area showing projected road segments and other features identified by Windes (1987, 1991) superimposed on an elevation model derived from LiDAR data (Dorshow, 2010, n.d.). Blue lines indicate drainage patterns. RS = road segment, *T* = ceramic transects. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Natural landscape agricultural suitability model criteria.

Composite GP model weight (%)	Analysis criteria	Data categories	Suitability score	Input data and remarks
25	Slope suitability	0–10%	5	Percent slope derived from conditioned 1 m DEM derived from 2010 NCALM LiDAR survey (Dorshow, 2010); Data gaps replaced with USGS 10 m DEMs. Manually edited terrain data to remove roads, paths and water diversion structures that are clearly historic
		10–15%	4	
		15–20%	3	
		20–30%	2	
		>30%	0	
25	Soil texture suitability	Sand dominated	5	NRCS Chaco Soils Study Data (Seaber et al., 1987) and University of New Mexico field data; Manually edited Soil boundaries using conditioned 2010 LiDAR DEM, aerial photos, and other geomorphic data
		Silt dominated	3	
		Clay dominated	1	
		Rock/water	NoData	
12.5	Depth to bedrock suitability	>3 m	5	NRCS Chaco Soils Study Data (Seaber et al., 1987) and UNM field data; Manually edited soil boundaries with conditioned 1 m LiDAR-based DEM, aerial photos, and other geomorphic data
		1–3 m	4	
		50–100 cm	3	
		10–50 cm	2	
		0–10 cm	1	
12.5	Flow distance suitability (Escavada Wash)	>3.5 km	5	Conditioned 1 meter DEM derived from 2010 LiDAR data
		2–3.5 km	4	
		1–2 km	3	
		500–1000 m	2	
		<500 m	1	
12.5	Overbank flooding suitability (non-catastrophic)	Chaco Canyon floor	5	Landforms extracted from conditioned 1 m LiDAR-based DEM, soils data, and imagery
		Major Chaco tributary Canyon floor	4	
		Moderate drainage margin	3	
		Minor drainage margin	2	
		Other areas	0	
12.5	Drainage proximity and flow potential	Flow length <= 700 m; drainage buffer distance = 50 m	5	Conditioned 1 meter DEM derived from 2010 LiDAR data
		Flow length > 0.7 km and < 1.4 km; drainage buffer distance = 40 m	4	
		Flow length > 1.4 km and < 2.8 km; drainage buffer distance = 30 m	3	
		Flow length > 2.8 km and < 5.6 km; drainage buffer distance = 20 m	2	
		Flow length > 5.6 km; drainage buffer distance = 10 m	1	
100	Natural agricultural suitability composite geoprocessing model	Very high agricultural potential	5	Weighted overlay using the six natural agricultural suitability component models listed above
		High agricultural Potential	4	
		Moderate agricultural potential	3	
		Low agricultural potential	2	
		Very low agricultural potential	1	

However, Pueblo Alto's influence on archaeological thought extends much further through the construction of "ritual" or "sacred landscape" models in which great houses outside Chaco are assumed to have been a ritual centers for a local community, based on the Pueblo Alto precedent that connects sacredness to great house architecture, topographic visibility and adjacent roads (Fowler and Stein, 1992; Stein and Lekson, 1992; Marshall, 1997; Van Dyke, 2007). The diminutive role assigned to agriculture at Pueblo Alto is partly responsible for the similarly attenuated role of farming in the ritual template used to interpret other great houses. And it is the absence of an explanatory role for agriculture that underlies the perception of Chaco as a "mysterious" place, which is a critical component in models that emphasize the "impractical and enigmatic aspects of Chacoan buildings" (Sofaer 1997, p. 94). We are not contesting the potential symbolic loading inherent in architecture, but in the following section we present a counter argument that agricultural production was integral to the Pueblo Alto community, and therefore should affect how Alto is used to infer ritual significance at great houses in general.

2.2 Agricultural suitability and the Pueblo Alto community

Dorshow (2010, n.d.) constructed a predictive model for potential agricultural productivity in Chaco ("Natural Agricultural Suitability") based on a geospatial analysis that integrates six critical natural factors relevant to agricultural production; slope, soil texture, soil depth, overbank flooding, drainage flow length, drainage proximity, and surface flow potential (Table 1). All analyses were done using ArcGIS 10.0 software (ESRI 2010) and an elevation database for Chaco Canyon obtained from airborne LiDAR data collected in 2010. Geological data were obtained from Weide et al. (1979). The basic analytical procedure involved the generation of

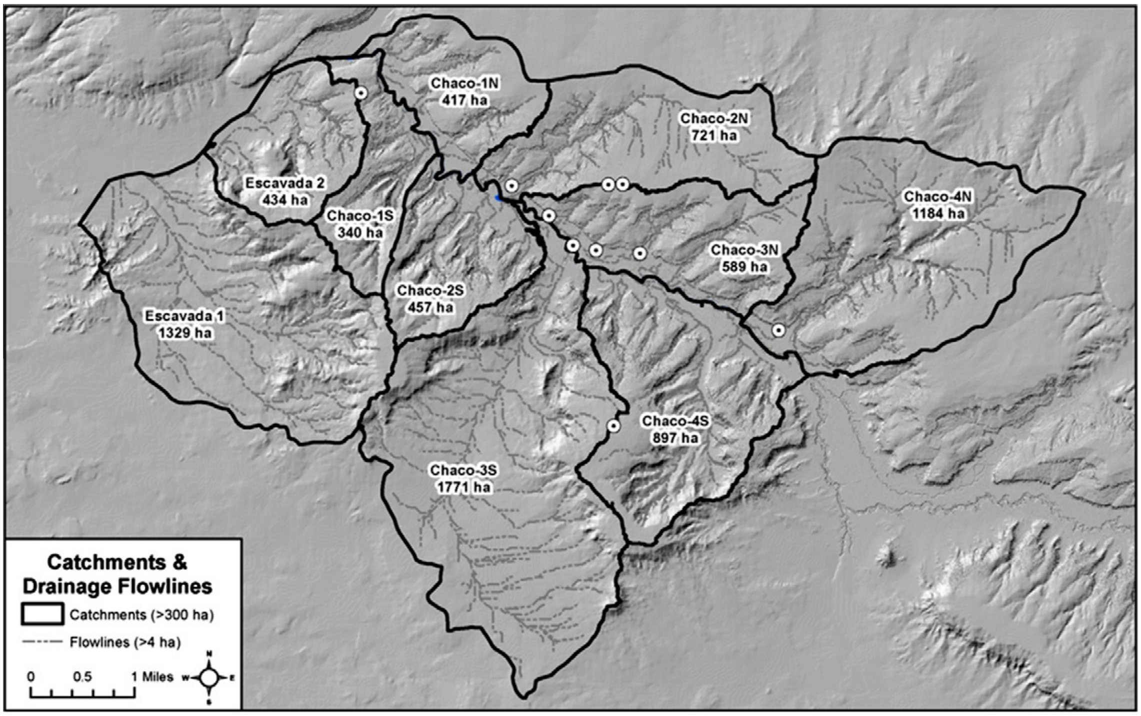

Fig. 5. Catchments exceeding 300 hectares in the western half (or "core") of Chaco Culture National Park. Circles indicate great house locations.

agricultural suitability rasters comprised of 1×1 m pixels having relative values ranging from 0 (lowest) to 5 (highest) for each of the natural factors based on agronomic and ethnographic studies of indigenous southwestern agriculture. A more detailed description of the analysis is found in Dorshow (2010, n. d.).

The foundation for the suitability analysis is hydrologic modeling because the environmental factors that determined suitability for agriculture in Chaco begin with water. Moisture availability is the critical factor determining whether plant cultivation (particularly maize) is possible (Bryan, 1929; Stewart and Donnelly, 1943; Kirkby, 1973) and availability is a function of the absolute amount that reaches a potential cultivation area and the ability of the soils in that location to retain what it receives (Dominguez and Kolm, 2005). There are other important factors, including slope, temperature and exposure, and soil chemistry, but moisture availability is absolutely paramount. Subsistence farmers in the Southwest historically coaxed successful maize crops from soils deemed agriculturally marginal or worse by modern agronomists (Forde, 1931; Page, 1940; Sandor et al., 2002, 2007; Homburg et al., 2005; Homburg and Sandor, 2010). Consequently we put primary explanatory emphasis on terrain-based hydrological models combined with soil characteristics affecting moisture retention, specifically texture and depth to bedrock. In our model-building we presume that *any* suitable location could have been cultivated and that passive water management at micro-scales was likely ("micro" includes small plots, simple lines of stones, brush weirs, berms, etc.) and that farmers took an active role in supplementing field locations with water and nutrients (see Forde, 1931, p. 363; Dominguez and Kolm, 2005, p. 737).

A custom ArcGIS geoprocessing model constructed by Dorshow (2010, n.d.) was used to create hydrologic catchments and stream channels from conditioned elevation data for the "Chaco Core," defined as the lower end of the canyon between Fajada Butte and the Escavada Wash. Ten catchments or "drainage units" of 300 ha or more were delineated in the analysis (Fig. 5). One of the largest is "Chaco 2-N", hereafter called the "Alto Mesa Drainage."

Although archaeologists have referred to the mesa top north of Pueblo Alto as a "rolling plain," it is actually an enclosed basin that drains to the Chaco floor through Clys Canyon (Fig. 6). Soils are predominantly sandy loams and loamy sands, preferred by maize farmers in the historical Southwest, with prominent dunes along the top rim of the basin. The drainage system has three major topographic elements; (1) an upper basin with moderate slopes draining mainly to the head of Clys Canyon, (2) Clys Canyon, a deep tributary that forms a series of steps or benches as it cuts down through differentially resistant sandstone s, and (3) the bottom of Clys Canyon at the level of the main canyon floor. Although there are areas of exposed bedrock in Clys Canyon, there are also deep alluvial sediments and active seeps or springs throughout its length.

The Alto Mesa drainage mostly scores in Moderate Suitability range (Figs. 7 and 8). Areas of exposed bedrock or shallow soils within Clys Canyon score Moderate to Low, as expected, but the alluvial zone scores Very High to High. There are significant patches of High to Moderate suitability in shallow depressions on the sandstone benches that separate the top of the mesa from the main canyon floor, especially on the west side of Clys Canyon, and several of these have high enough densities of artifacts that they are designated as sites by the National Park Service (Fig. 9). The lowest portion of the drainage, at the floor of the main canyon, has a Very High value.

Linear zones with High Suitability scores corresponding to shallow drainages in the upper basin of the Alto Mesa unit are especially important because they emphasize the potential significance of micro-topographic features within larger areas that score lower on our suitability scale (Fig. 7). These shallow drainages intersect extensive areas of moderate slope, meaning that flow in those drainages might easily have been diverted onto adjacent slopes with simple devices such as brush weirs, thus raising the production potential of those areas. Scores for agricultural potential vary across five elevation zones within the Alto Mesa catchment (Figs. 7 and 8, Table 2). Although the highest suitability scores are dominant in lower terrain, the vast majority of arable land within this catchment occurs at higher elevations.

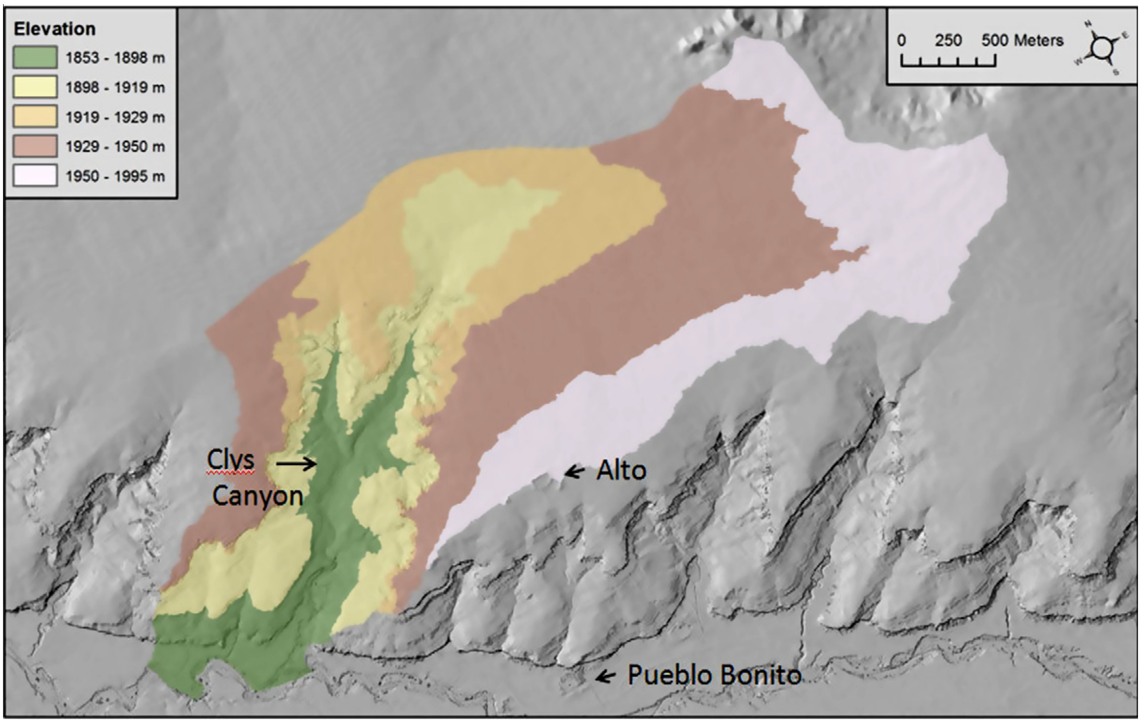

Fig. 6. Alto Mesa drainage unit showing elevation proportions.

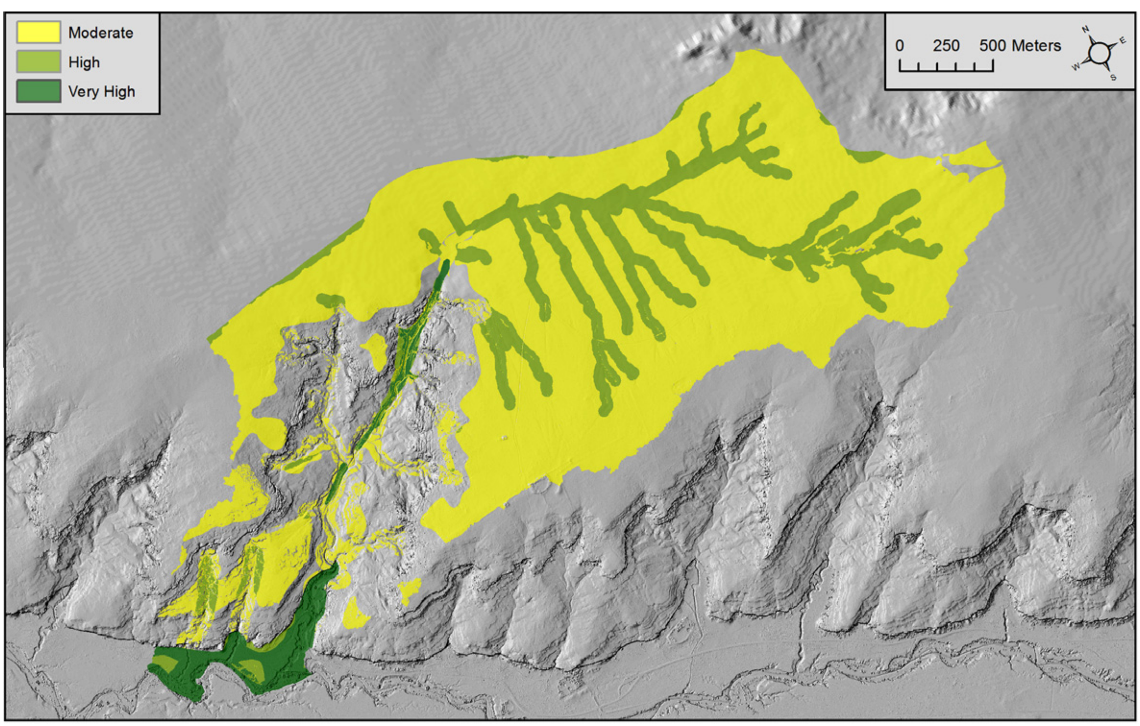

Fig. 7. Alto Mesa drainage unit showing distribution of potential agricultural suitability.

These results direct our attention to a neglected experimental study of maize production conducted by Park Service archaeologists in the late 1970s (Toll et al., 1985). Ten small cultivated plots were established at locations between Fajada Butte and Penasco Blanco. Each was planted with modern varieties of Hopi maize, fenced to exclude pests, hand-watered and weeded. Two plots were near Pueblo Alto, one approximately a kilometer to the east in a small pocket of sand that researchers thought might have been an artificial terrace, the second about 1.2 km north in a shallow, sandy drainage. This latter plot (No. 4) was the most productive of the ten, with the tallest plants and a 65.6% germination rate (Toll et al., 1985, p. 92). Additionally, two bean plants matured successfully in Plot No. 4, apparently the only plot in which this happened. Obviously we would expect farming novices to have less success growing maize in Chaco than the agrarians who built a vibrant society in the canyon a millennium ago (see Toll et al., 1985,

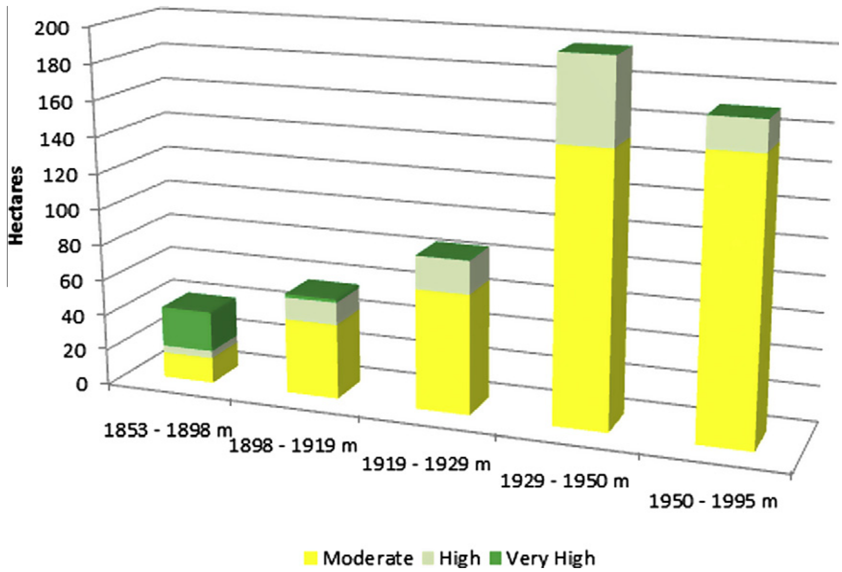

Fig. 8. Bar chart showing proportion of potential agricultural suitability scores in the Alto Mesa drainage unit by elevation.

Fig. 9. Site 29SJ1123, an example of a small catchment on bedrock in Clys Canyon that captures sediment and runoff creating micro-environments suitable for plant cultivation (Fig. 6; the National Park Service requests that the exact location not be published). There are hundreds of similar geologic features throughout Chaco. 29SJ1123 has a high density of lithic debitage and ceramic material that cannot have washed into the site as there are no archaeological sites on the slope above the catchment.

Table 2
Catchment 2 N summary.

	Natural agricultural suitability class		Hectares	Percent of catchment chaco 2 N (%)	
Potentially arable lands	Class 1		50.3	7.13	
	Class 2		105.7	14.98	
	Class 3 (moderate)		426.0	60.38	
	Class 4 (high)		99.2	14.06	
	Class 5 (very high)		24.3	3.44	
			705.4504	100.00	
Values in hectares by elevation	1853–1898 m	1898–1919 m	1919–1929 m	1929–1950 m	1950–1995 m
Moderate	14	42	67	150	153
High	4	13	19	47	17
Very high	22	2			

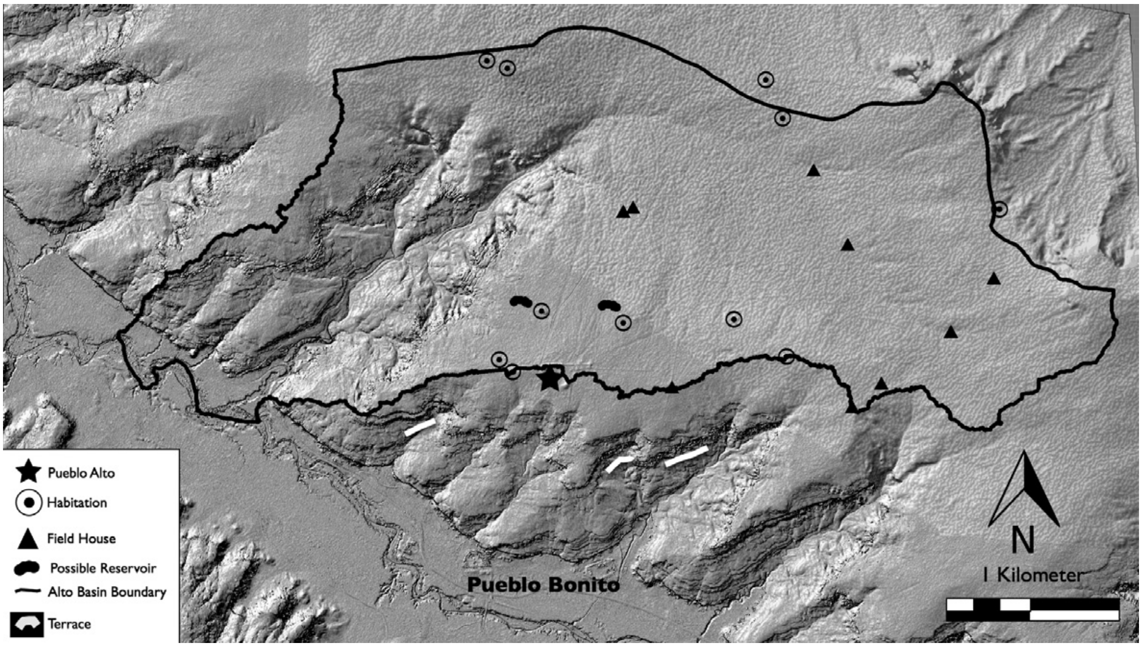

Fig. 10. Archaeological structures and features in the Alto Mesa drainage. Habitation structures consist of multiple-room masonry buildings with dense artifact middens. Field houses are single room structures with a low density of surface artifacts. One large habitation site is located just outside the northern drainage boundary but we have included it because it is on the drainage boundary and overlooks the basin.

p. 126), so the fact that these plots experienced any maize growth at all indicates that local crop production was certainly possible, and as Dominguez and Kolm (2005) indicate for the modern Hopi, a function of a deep ecological knowledge of micro-habitats. To put a finer point on it, the mesa top around Pueblo Alto is so suitable for maize and bean cultivation today that even inexperienced archaeologists can get plants to grow there.

2.3 Alto mesa settlement pattern and evidence for food production

The Alto community complex defined by Park Service researchers included six discrete residential buildings with an estimated 247 + rooms located within 200 m of the great house (Windes, 1987, p. 79–94), of which more than half (56%) date to the Late Classic (or McElmo phase) sometime in the 12th century (Fig. 3). However, there are eight additional residential buildings in the drainage basin that were not assigned to the Alto community complex, comprising at least 100 rooms (Fig. 10). Hydrological modeling and recent pedestrian survey indicate there are shallow basins formed behind artificial berms associated with two of the 12th century buildings. One is adjacent to Rabbit Ruin and has a possible head gate on the west side, the other is adjacent to 29SJ1979 (Fig. 11). Neither feature has been identified previously, but Windes (1987, p. 98; 1991) labeled the drainage into the Rabbit Ruin basin as Road Segment 43 (Fig. 2). Although a reservoir function has have not been confirmed by excavation, (1) these features currently impound slope runoff, (2) they occur along the same elevation contours, and (3) and each is adjacent to residential structure. Small reservoirs occur in Chaco but are uncommon and do not figure in studies of agricultural production.[1] At least eight features identified as field houses were located by pedestrian surveys in the Alto Mesa drainage unit, mostly along the basin rim (Fig. 10). Check dams are also present but inconsistently recorded by different survey crews, although they often occur in the swales that define "roads," especially near the head of Clys Canyon.

The presence of water control features around Pueblo Alto raises the question of whether at least some of the "roads" are actually remnants of a system for directing surface runoff. Ware and Gumerman (1977, p. 146) observed that many of the characteristics of "land routes" around Pueblo Alto "are associated with rechanneling of surface runoff" because of the way that roads intersect slopes. Archaeological excavations in the most prominent roadways adjacent to Pueblo Alto did not find elaborate construction as might be expected with formal transport routes, but instead revealed simple removal of sediment to shallow impermeable strata, occasionally bordered by rough stone curbing, "… usually on the downslope side, as if the sandstone were placed there to retard erosion" (Ware and Gumerman, 1977, p. 148). Reinforcement of the down slope sides of artificial channels is a common irrigation technique among the historic Native American farmers of the Southwest, and one that Vivian (1972) documented in canals situated along the main Chaco floor (also Judd, 1954).

Most but not all roads on Alto Mesa originate or terminate at residential structures, while all cross the basin terrain at angles that intercept runoff (Fig. 12). The relatively wide but shallow linear features could have collected runoff that was easily redirected laterally with temporary earthen berms or brush weirs (see Forde, 1931; Bryan, 1929). Gillespie and Love (1979) cross-sectioned a well-defined canal in the canyon bottom that had a flat, shallow profile like road segments excavated around Pueblo Alto, indicating that this geometry was utilized in definite water control efforts. Similar channels make particular sense on slopes, since a flat cross-section inhibits an increase in water velocity associated with confinement in deep narrow channels.

Janes (2005) offered a similar explanation – or reinterpretation – of road segments identified at two Chaco great houses, Standing Rock Pueblo and Pueblo Pintado (48 km south and 28 km east of

[1] It is possible that these features were constructed more recently. The area around Alto was used as a horse pasture by the Wetherill family in the late 19th century and they built a large bermed reservoir by Pueblo Bonito. However, there are no historical materials associated with these features and they are physically linked to prehistoric buildings. It would be helpful to cross-section these features to determine their age but until then we are comfortable assuming that they were part of the Bonito phase physical landscape.

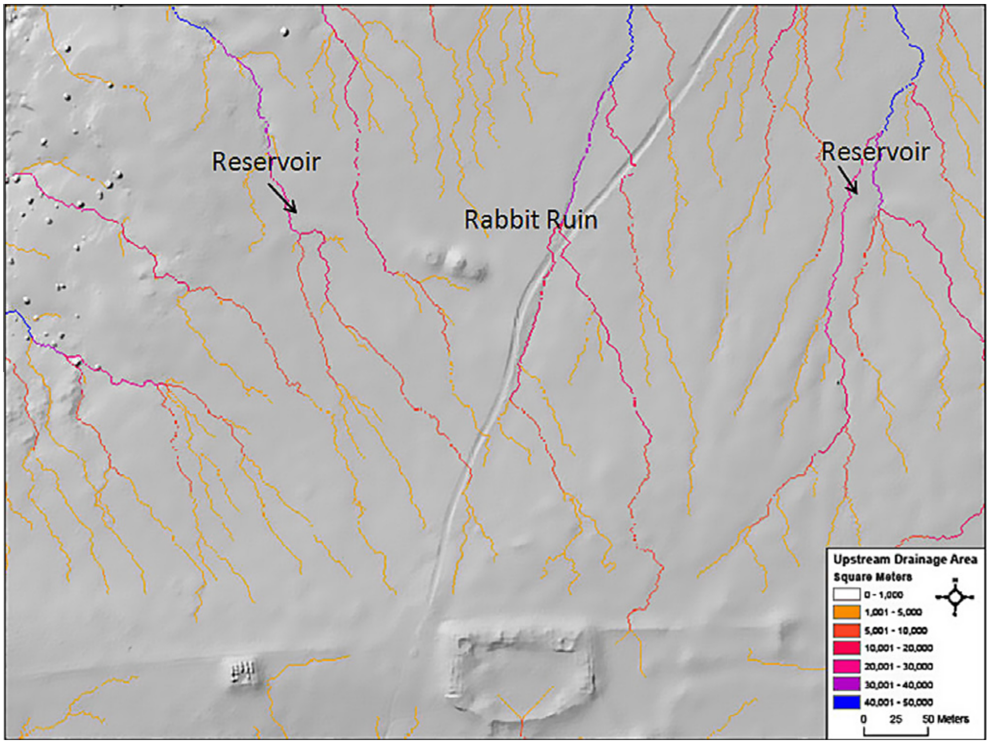

Fig. 11. Two possible reservoirs in the vicinity of Pueblo Alto with associated drainage catchments.

Pueblo Bonito respectively). He observed that constructed linear features at Standing Rock assumed to have been roads conveyed water away from the great house and into an adjacent drainage, while artificial mounds associated with the great house diverted runoff into these features. Janes suggested that this water would have reached potential fields or reservoirs. Essentially the same topographic situation existed at Pueblo Pintado, except that mounds have a more dramatic role in intercepting and redirecting sheet wash flowing toward the great house (Janes, 2005, p. 50; see also Worman and Matteson, 2010). He allows for the possibility that these linear features might have had multiple functions, as roads and water control technology but notes that given their topographic position they had to have conveyed water down slope and the builders were surely aware this would happen.

Since any road on a slope will collect water, it is difficult to conclusively argue for a deliberate water control function as opposed to an unintended consequence and obviously such features could have been multi-functional. However, we accept Jane's assumption that given the skill of Chaco builders in engineering huge, free-standing masonry structures, as well as their adeptness at controlling water on the canyon floor, they would have been keenly aware of the effect on surface runoff resulting from excavating shallow linear channels oblique to the slope contours around Pueblo Alto. We are not suggesting that all linear features interpreted as roads were built to control runoff but there is an empirical relationship between many of these features and local environmental variables relevant to agricultural production, whereas it has yet to be shown that these features were designed and built to provide routes for foot travel.

In addition to water-control features in the Alto Mesa basin, there are three massive man-made stone terraces on the geological benches just south of Pueblo Alto that may have been used for plant cultivation, although there has been no excavation or coring to test this possibility (Figs. 4 and 10). Each terrace is a large feature representing a great deal of labor in construction occupying a topographic position that receives significant amounts of potential runoff and sediment from the mesa top. These terraces have moderate agricultural suitability scores and we believe they represented a significant contribution to potential food production in the area around Pueblo Alto (Figs. 13 and 14, Tables 3 and 4).

Two independent but circumstantial lines of evidence support our view that the Alto Mesa basin was an important part of the Chaco agricultural system. First, pollen data from excavations at Pueblo Alto indicate that maize plants were processed at the site and therefore probably locally grown. Maize pollen is heavy and does not travel far. For example, Hall (2010, p. 133) reports that about 90% of pollen recovered from experimental plots occurs within 25 m of the field. Therefore high grain counts in archaeological sites indicate either nearby fields or presence of plant parts, such a leaves, not simply (or even) cobs (Geib and Smith, 2008). Multiple sampling locations at Pueblo Alto produced maize pollen frequencies that are significantly larger than expected by the null hypothesis (i.e., they depart from a 1:1 correspondence with sample size), meaning that these patterns indicate a strong cultural process (Fig. 15). Moreover, while most of the Alto pollen samples fall squarely within the range of maize pollen recovered from other excavated sites, several samples produced the highest percentages of maize found in any Chaco context, meaning that Pueblo Alto shows one of the strongest signals for on-site processing of maize plants.[2] Similarly, ubiquity measures for maize macrofossils are the same for Pueblo Alto as other excavated sites in Chaco (Toll, 1984).

A second circumstantial argument that the Alto Mesa drainage unit was integral to food production during the Bonito phase lies in the probability of catastrophic flooding destroying agricultural

[2] The Chaco maize pollen does not offer any insights about the related question of "agricultural dependency." Maize was clearly grown in Chaco; how much was grown, or how much was consumed, cannot be determined from the pollen record. However, given the right sampling program it may be feasible one day to determine how much of the canyon was farmed, which would offer the kind of empirical confirmation that any production model requires, including the one presented herein.

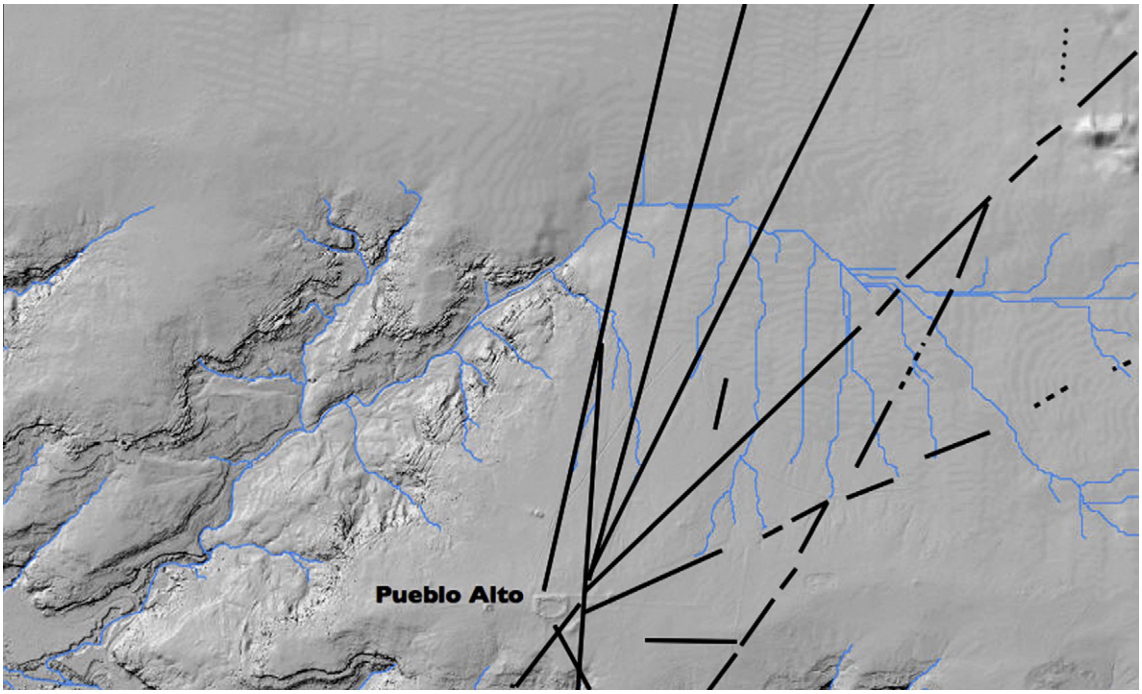

Fig. 12. Major roads defined by Kincaid et al. (1983) imposed on a LiDAR derived surface model of the upper Alto Mesa drainage unit. Broken lines reflect gaps in the features or estimated projections. Blue lines indicate major drainages. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

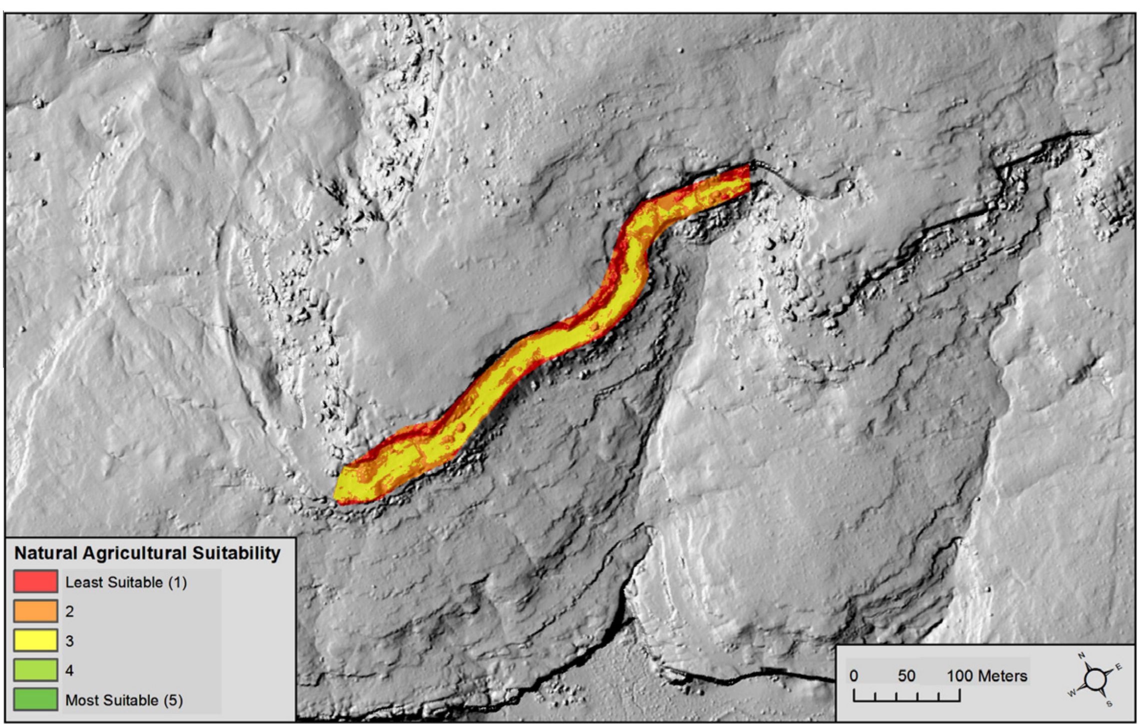

Fig. 13. Artificial terrace southwest of Pueblo Alto and above the canyon floor (Feature RS 34 in Fig. 4). This feature represents nearly one hectare of moderately suitable agricultural soils.

fields on the canyon floor. A simple model of overbank flooding (run for incised and non-incised canyon floor) indicates that mesa tops are least susceptible to catastrophic flooding and the canyon floor, especially where alluvial fans form at the base of tributary drainages, are the most susceptible to destructive flooding (Fig. 16). In other words, since canyon floor fields had the highest

Fig. 14. Artificial terrace (RS 34) facing northeast.

Table 3
Scenario 1: maximum yield estimates for catchment Chaco 2 N.

Natural agricultural suitability class	Cell count	Hectares	Clumps* per HA	Max yield per clump**	Potential maize yield (kg)
Moderate	4,259,778	426.0	686	0.2	58,444
High	992,008	99.2	686	0.2	13,610
Very high	242,831	24.3	686	0.2	3332
				Total	75,386

*Following the methods of Manolescu (1995, Table 7), the estimated number of clumps (maize plant clusters typical of traditional Hopi agriculture) per hectare is approximately 686 (2.7 m spacing between alternating planted and fallow patches) and the corresponding edible maize is about 0.2 kg per clump.

Table 4
Scenario 2: conservative maize yield estimates for catchment Chaco 2 N.

Natural agricultural suitability class	Cell count	Hectares	Clumps* per HA	Max yield per clump	Potential maize yield (kg)
Moderate	4,259,778	426.0	229	0.07	6494
High	992,008	99.2	457	0.13	6049
Very high	242,831	24.3	686	0.20	3332
				Total	15,874

*Following the methods of Manolescu (1995, Table 7), the estimated number of clumps (maize plant clusters typical of traditional Hopi agriculture) per hectare is approximately 686 (2.7 m spacing between alternating planted and fallow patches) and the corresponding edible maize is about 0.2 kg per clump.

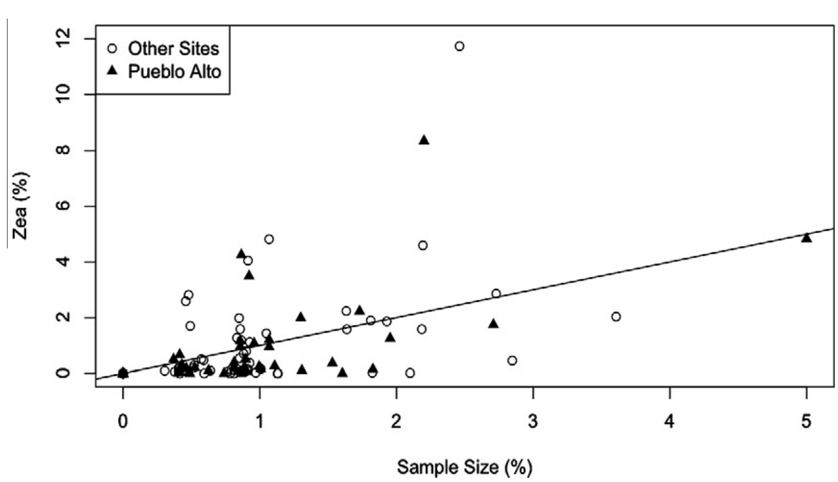

Fig. 15. Pollen data (percent occurrence of Zea mays versus percent occurrence of sample) from archaeological sites in Chaco Canyon and the San Juan Basin. Zea mays counts from each site were divided by total Zea pollen counts from all sites. Sample size was calculated by dividing individual site totals by total pollen from all sites. The line represents an idealized model of Zea mays varying with sample size with a 1:1 ratio. The Pueblo Alto pollen samples are consistent with results from other archaeological sites and in some cases exceed expectations for a simple sample size effect. Data sources: Cully (1985) and unpublished results from ongoing analyses conducted by Susan Smith and Suzanne Fish for the University of New Mexico.

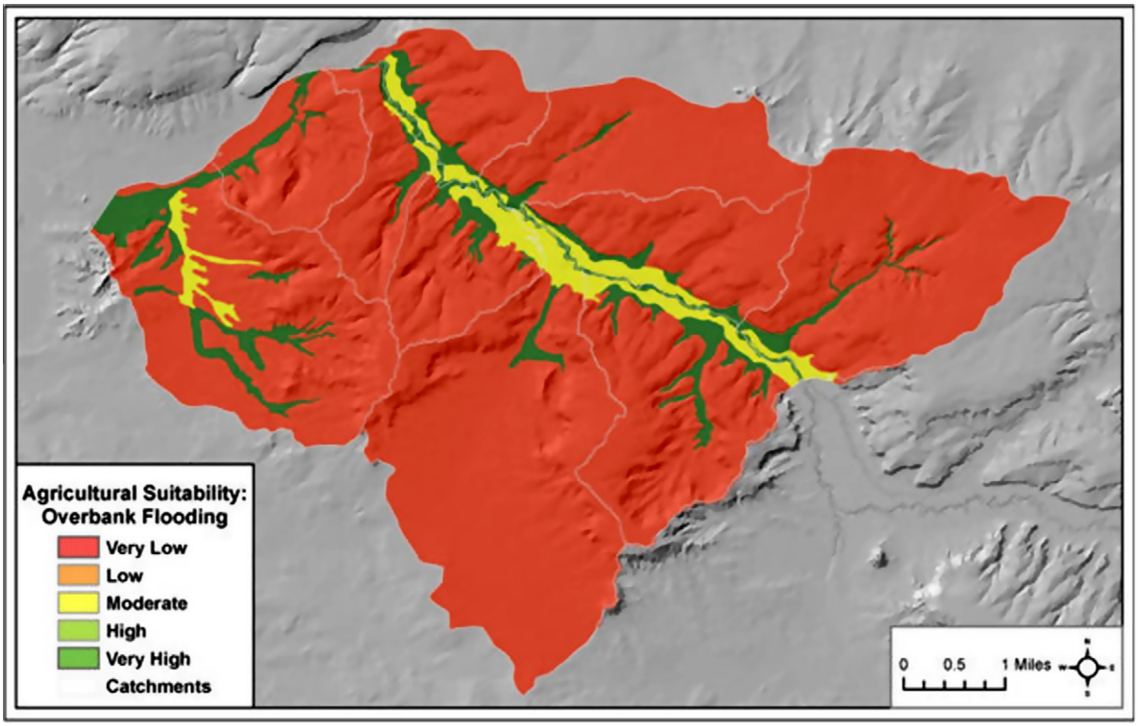

Fig. 16. Model of potential overbank flooding risk.

probability of crop loss from flooding, agricultural areas located above the floodplain (including terracing) could have provided "insurance" production.

3. Implications: the alto community revised

3.1 Estimating agricultural potential in Chaco

Previous studies of agricultural potential in Chaco exclusively focused on the tributary sand fans and dunes found in the canyon bottom as the primary or sole areas for plant cultivation, especially in locations near great houses (Vivian, 1972, 1990; Loose and Lyons, 1976; Benson, 2011), with the exception of a single experimental plot established on the mesa near Pueblo Alto in 1977 (Toll et al., 1985). None of the published agricultural productivity studies for Chaco during the Bonito phase include mesa tops as production areas (Loose and Lyons, 1976; Vivian, 1990; Sebastian, 1992; Benson, 2011). These studies estimated agricultural production on the basis of actual or hypothesized locations of formal, gridded agricultural fields at the entrances of north side tributaries on the canyon floor. Just one of these field systems (east of Chetro Ketl) has been mapped and excavated and probably dates in the 12th century AD (Loose and Lyons, 1976; Force et al., 2002). Most researchers also assume that sand dunes on the south side of the canyon floor were used for *akchin* (rainfall) farming, as at modern Hopi. Individual households almost certainly dispersed their fields to reduce the risk of crop loss and enhance the probability of access to moisture (Ford, 1972; Homburg et al., 2005), although no one has attempted to link fields to discrete households in Chaco. Even though three great houses are on the mesas above the canyon (Pueblo Alto, Peñasco Blanco and Tsin Kletzin), the mesas have been viewed mainly as the source of runoff into the lower canyon rather than production zones.

In contrast to these previous analyses we argue that the mesas and escarpments above the main canyon floor were integral to Chaco agriculture for cultivation as well as runoff. In a parallel study, Dorshow (submitted for publication) has shown that the other two mesa top great houses (Peñasco Blanco and Tsin Kletzin) also are associated with locations of High agricultural suitability (Figs. 17 and 18). We estimate conservatively that potential maize production in the Alto Mesa basin in an average climate year for the Bonito Phase would range between 15,874 and 75,386 kg (252–1197 bushels) (Table 5). For comparison, Hegmon (1989) reports that the average Hopi household required ca. 1017 kg of maize annually to meet basic subsistence needs; applying that figure to the Alto data produces a range of 15–68 households, which would rather neatly fit between population estimates for Pueblo Alto (Windes, 1987) and Alto combined with one or more additional great houses (see Bernardini, 1999). We emphasize strongly that these are just estimates, but the calculations show that the Alto Mesa could have provided a significant part of the canyon population's annual maize production.

It is important to point out that Benson (2011, p. 101) characterized soils in the Chaco "Halo" (or region) as generally "non-optimal for the production of maize," and "very unproductive," and considers floodplain soils in Chaco Canyon as particularly non-optimal for growing maize. His analysis of variation in soil chemistry over large portions of the Southwest indicates that few places are optimal across the range of factors relevant to maize cultivation when generalized to large regions. It is more important, as he acknowledges (Benson, 2011, p. 103), that local conditions conducive to maize farming occur throughout the Chaco region in discrete *patches*, a feature of Chaco Canyon as well, and that ultimately water availability is the dominant variable, followed by "solar radiation, nutrients and well-structured soil" (2011:4).

Researchers have understood since the 1920s that the main Chaco floodplain in its current configuration is poorly suited for maize farming because surface sediments are mainly silty clays originating outside the canyon (Bryan, 1954; Judd, 1954; Love, 1983). In contrast, tributary canyons exhibit good conditions for cultivation consisting of deep loamy sands or sand dunes, organic

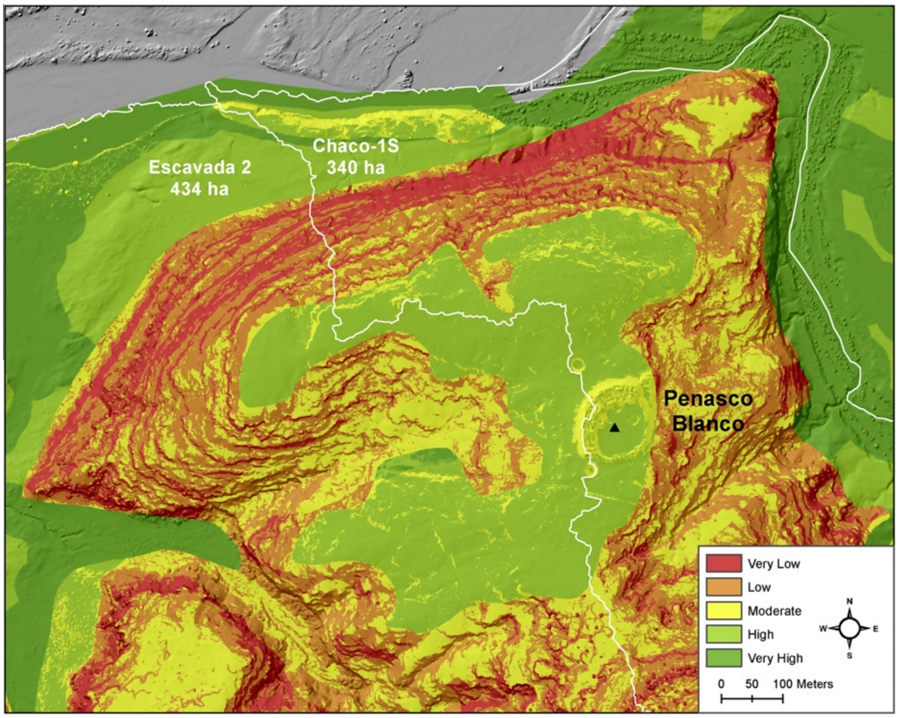

Fig. 17. Potential agricultural suitability model for Peñasco Blanco (see Fig. 1). The area of "Very High" potential on the main canyon floodplain (far right side of image) does not reflect soil chemistry studies which suggest poor growing conditions at the *modern* surface throughout much of the central floor of the canyon (Judd, 1954; Benson, 2011). However, the actual Bonito Phase agricultural fields or cultivation areas are buried and we believe the model accurately predicts areas of optimal hydrological conditions for farming.

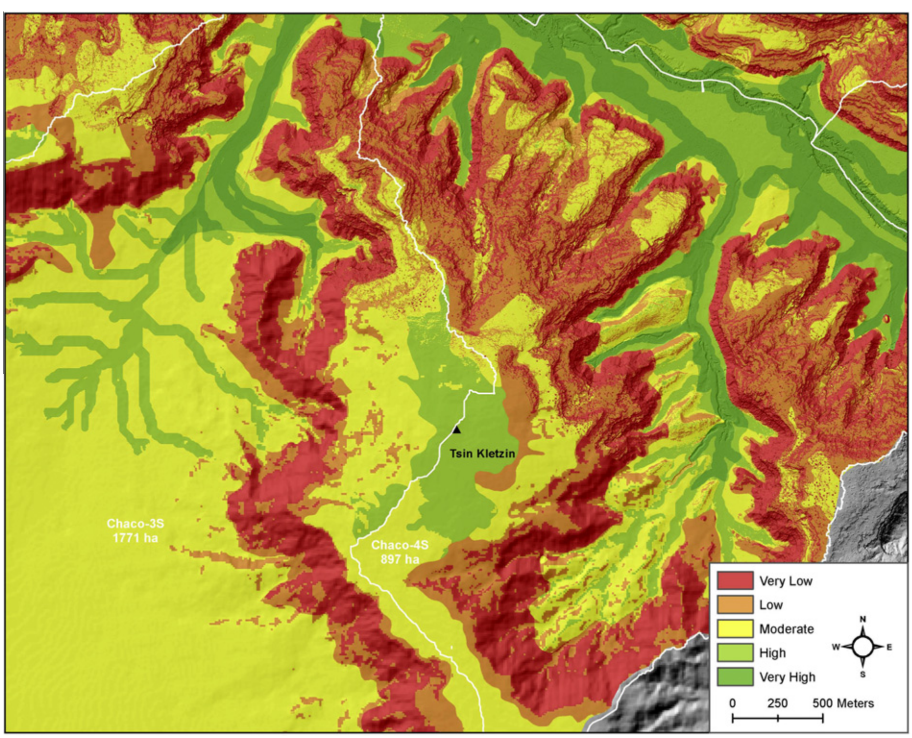

Fig. 18. Potential agricultural suitability model for Tsin Kletzin (see Fig. 1). As in Fig. 17, some parts of the main canyon floor that score "Very High" in potential productivity are likely over-valued because surface sediments in the center of the floodplain derived from upstream sources outside the canyon are not ideal for cultivation. In this case though, the model shows the significance of tributary sources of loamy sand containing mesa-top nutrients combined with runoff in the form of linear dendritic patterns of Very High production potential that extend onto the floodplain. In fact, the model suggests that south side tributaries were probably much more important for agriculture than assumed in current reconstructions of Chaco farming.

detritus from mesa top vegetation, and runoff. Recent soils studies such as Benson's are based on modern surface conditions but it is likely that much of the actual cultivated surface in the canyon during the Bonito Phase is now buried. Extending our analytic scope to

Table 5
Maximum yield estimates for terrace 1.

Nat. agric. suitability class	Cell count	Hectares	Clumps per HA	Max yield per clump	Potential maize yield (kg)
Moderate	3663	0.4	686	0.2	50
High	6749	0.7	686	0.2	93
Very high	5	0.0	686	0.2	0
				Total	143

mesas and escarpments above the floodplain dramatically enhances estimates of agriculturally suitable lands in Chaco.

For this reason we suggest that the idea that mesa great houses were only tangentially connected to food production needs to be revised. We hypothesize just the opposite, that great houses on the mesas were able to take advantage of (or control) important components of the local agrarian economy. We recognize that these buildings have attributes, such as lines-of-sight, that were undoubtedly important to the builders, but the fact is that the mesa great houses co-vary with moderate to high suitability agricultural zones and this is almost certainly not a coincidence.

3.2 Great house user groups

Our predictive model identifies most of the Alto Mesa drainage unit as a potential agricultural zone. Pueblo Alto was obviously the focal point of occupation in this zone but we suggest that *all* residential sites in or immediately adjacent to drainage were part of a single user group (i.e., the group with access to a naturally defined production zone), and therefore the user group was *larger* than the Pueblo Alto community defined by the Chaco Project (Windes, 1987, 1991). We do not assume that this user group was a single cohesive social unit, although we think it is likely that proximity and access to local suitable agricultural lands indicate coordination among these users and therefore this group probably conformed to the community definition of a regularly interacting residential group. Most of the Alto Mesa residential structures occupy locations along the top of the drainage, allowing easy access to and sweeping view of adjacent drainages, so it is possible that the Alto user group (or segments thereof) had fields distributed in neighboring production zones as well.

Given the exposed conditions on the mesa top and extremely cold Chaco winters during the modern era (the average January temperature is less than 2 °C, while the lowest recorded temperature in the past century is – 34.4 °C), as well as significant distances to water and fuel sources, we suspect that the residential architecture around the top of the Alto Mesa basin reflects mainly occupation during the growing season[3] and that the Pueblo Alto great house might have been a winter "village" for the user group. However, we think it is plausible that even Pueblo Alto was mostly a summer settlement (compare with Windes et al., 2000), which could help account for the lack of a great kiva (expensive non-domestic architecture) and the small number of rooms relative to the architectural footprint (other great houses create highly insulated internal space by massing rooms in multiple stories).

Occupation on the mesa preceded the construction of Pueblo Alto, as there are earlier rooms found below excavated Classic period floors, as well 10th century ceramics in the Alto mound and on the surface of several mesa room blocks. Only part of the conventional Alto community dates to the Classic Bonito Phase (ca. AD 1020 to 1100), since New Alto, Rabbit Ruin and some road segments were built later in the 12th century. Consequently it seems clear that Alto Mesa was used throughout the Bonito phase (ca. AD 860 to 1140), and land use may even have intensified during the 12th century. Moreover, Wills (2009) has argued that the Classic and Late ("McElmo") portions of the Bonito phase represent two different populations (with respect to cultural identity) separated by a period of settlement abandonment. The empirical record is therefore quite clear that the Alto Mesa drainage basin was an important long-term component in the Chaco residential system, predating and postdating the explosive construction of great houses in the 11th century, and we suggest that this prolonged significance was a function of local agricultural potential.

3.3 Chaco "Roads"

Our understanding of Chaco roads suffers from the same paucity of empirical evidence that characterizes great house histories. Two decades ago Roney (1992) pointed out that transportation was an unlikely function for most linear features identified as roads, that archaeologists had often relied more on enthusiasm than empiricism in identifying roads, and that chronological control was essentially non-existent. Little has changed since but expansive models for road function based on ritual performance or political control nevertheless abound, including a pointed dismissal of Roney's conclusions (Lekson, 2006, p. 34). Our terrain modeling based on airborne Lidar (Dorshow, 2010, n.d.) combined with pedestrian survey on Alto Mesa suggests multiple possible functions for the more prominent constructed "linealities" rather than a clear-cut role as roads, but many other mapped road segments appear to exist only in the eye of the beholder (Vivian, 1997), a problem that might be resolved by new excavation and remote sensing. We anticipate that Janes (2005) is correct that many prehispanic "roads" throughout the Chaco region represent various functions; some may have been water control features, some really were roads for traveling between living communities, some were ritual features (perhaps analogous to historic Pueblo "raceways"), and some may have been purely cosmographic. We need to sort out these functions on a *case by case basis* in order to understand Chaco and that requires testing models as well as building them.

3.4 Regional settlement patterns and communities

Chaco Canyon is widely perceived as the "center place" in a vast regional network of communities and our conclusion that the Alto Mesa "user group" was larger than the conventional Pueblo Alto great house community has implications for the overall Bonito Phase political economy associated with this entity. Peterson and Drennan (2005) observe that understanding prehistoric regional polities depends foremost on how local communities are identified and then interpreted. Communities comprising a regional entity are the nodes through which information, material, and people moved and our ability to discover systemic linkages among polity members follows from how well we are able to grasp the boundary conditions that defined actual groups in the past. Chaco specialists commonly argue that the great house communities were discrete

[3] Some of the smaller roomblocks or individual rooms on the mesa were described during surveys in the early 1970s as "road-related" structures because of proximity to linear features interpreted as prehistoric roads. None of these have been excavated and so far at least, there are no published criteria for inferring a function connected to road use other than proximity. We have elected to avoid adopting these interpretations because they cannot or have not been verified.

residential social groups defined by the proximity of dwellings and characterized by regular interaction among members (Doyel et al., 1984; Windes et al., 2000; Varien, 2000; Kantner and Kintigh, 2006). Yet any survey of the Chaco great house literature shows that there are no standardized criteria for defining a residential community or measuring connectivity (Powers et al., 1983; Kantner and Mahoney, 2000; Lekson, 2006). Mahoney (2000, pp. 19–20) demonstrated that although Chaco communities are typically defined as all residential structures within a 1–2 km radius of a great house, few of these appear to have been demographically viable for any length of time based on inferred population size, implying more extensive geographic relationships (also Durand and Durand, 2000; Gilpin, 2003). Moreover, excavations nearly always reveal complex and punctuated occupational histories that are not evident in surface features (McKenna et al., 1986; Windes, 1987; Reed, 2006), meaning that static settlement pattern models conflate an unknown amount of temporal variation and historical ambiguity, including skewing toward the most intensive and/or latest periods of occupation.

On the basis of our model of agricultural potential at Pueblo Alto, we suggest that a more accurate appreciation for Chaco community boundaries can be obtained from predictive approaches to local agricultural productivity than by arbitrarily imposing linear boundaries such as 1–2 km radii or similar intuitive constraints. If Chaco farmers shifted residential locales seasonally, dispersing into smaller settlements (perhaps kin-groups) nearer agricultural fields or plots, analogously to historical Pueblo settlement systems (Ford, 1972; Ferguson and Hart, 1985; Rothschild et al., 1993), it seems probable that the aggregate number of Chacoan buildings in any time period was produced by seasonal occupation of different structures. Perhaps more significantly, we endorse the likelihood in some cases *single social groups in and around Chaco built and owned multiple great houses*, each of which may have had distinctive occupational dynamics determined by land use systems and demographic trends. For example, Pueblo Alto may have been the dominant residential building on Alto Mesa, but it might also have been occupied most intensively in the summer as a seasonal projection of a social group tethered to some other great house. We might expect any such tethering to be around the oldest or longest established great houses in the canyon, such as Pueblo Bonito or Peñasco Blanco, presumably those with greater social seniority, again analogously to historical Pueblo societies (Kroeber, 1916; Eggan, 1950; Dozier, 1970; Ortiz, 1969; Levy, 1992).

Other researchers have suggested that there could have been close ties between canyon great houses and great houses ("outliers") located some distance away, perhaps based on kinship, that provided social conduits for exchange of goods and people (Doyel et al., 1984; Toll, 2006; King, 2003). That idea makes good sense to us, given studies of source areas for artifacts found in Chaco, but we also feel it is plausible that some or many outliers were seasonal affiliates of other great houses. If multiple great houses and surrounding small sites were linked in a single social group, perhaps what anthropologists like to call "villages," then we almost certainly misunderstand the nature of regional polities if our analyses are based solely on static models of settlement distribution and site size hierarchies (see Schelberg, 1984; Neitzel, 1999; Lekson, 2006, 2009; consider Stone, 1991). Indeed, we argue that *in general* current political models of the Chaco regional phenomenon overestimate the number of constituent communities at any given time during the Bonito Phase because individual great houses outside the canyon are treated as autonomous social units. However, as Kantner and Kintigh (2006; also Vivian, 2005; Reed, 2006) illustrate well, there is so little substantive archaeological data from all but a half dozen Chaco great houses that we lack even minimal confidence in dating the occupational histories of the nearly 200 great house communities attributed to the Chaco regional system. We simply have no firm grasp of historical dynamics at the regional level and few signs that the situation will improve in the future, but that still does not justify uncritical use of interpretive templates.

4. Conclusion

Farming in Chaco Canyon was probably not as limited as many researchers have assumed; what may be more problematic is why agriculture seems to have such a small and poorly documented role in current sociopolitical models of the Bonito Phase. Cutting edge scholarly literature on Chaco is rich in ideas about religion and cosmology, or debates about the nature and exercise of political power, but decidedly impoverished in grasping the basic economic foundation upon which Chaco society was built (Earle, 2001). The staple diet of southwestern Pueblos does not appear to have changed much during the past two millennia (Coltrain et al., 2007) and so we reasonably seek the connection between farming and great house construction in the organization of production rather than diet (Sebastian, 2004; Wills, 2005). Likewise, given how central farming is to historic Pueblo culture and religion, we should expect cultivation to have been prominent in Bonito Phase cosmology. Unfortunately, incentives for acquiring better information about food production in Chaco are absent in the current dominant interpretive templates that lack or dismiss economic components. By comparison, researchers investigating the emergence of cosmological systems among farmers in other parts of the world have made food production a central feature of explanatory models (Brown, 1997; Bradley, 2005; Roberts and Rosen, 2009).

We are neither arguing that understanding the economic role of agriculture in the construction of great houses is easy, nor are we suggesting that cosmological approaches to Chaco architecture are wrong. If it was easy to grasp the relationship between southwestern farming and culture change in the past there would be little need for the ongoing multidisciplinary studies of prehistoric agriculture that continue to drive much of the archaeological research in the region beyond Chaco. If the appearance – or abandonment – of great house communities was easy to explain in terms of farming, it would have been done long ago. We have the utmost respect and appreciation for the difficulties that other researchers have encountered in addressing this crucial aspect of Chaco's complex history. What we have attempted to show is that a major part of the potential agricultural landscape in Chaco has not figured in previous attempts to estimate productivity. We hope that reintroducing farming to archaeological thinking about Chaco through deductive model-building and geospatial analysis reveals how much more we can know about the Bonito Phase and at least one way in which we can begin to evaluate some of the models proposed as explanations.

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