# FLOODWATER FARMING, DISCONTINUOUS EPHEMERAL STREAMS, AND PUEBLOAN ABANDONMENT IN SOUTHWESTERN COLORADO

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*Geoarchaeological study on the southern piedmont of Sleeping Ute Mountain in southwestern Colorado indicates the presence of discontinuous ephemeral streams that were the foci of episodic Puebloan occupation between A.D. 600s and 1280. Characterized by arroyos, discontinuous ephemeral streams contain alternating aggrading and degrading reaches and are well suited for ak chin floodwater agriculture. Episodic Puebloan abandonment of the southern piedmont correlates with periods of drought but does not appear to be linked to stream entrenchment. We question a priori assumptions of droughts correlated to stream entrenchment and urge caution in the use of drought-arroyo models for settlement shifts in alluvial flood plains without supporting stratigraphic or geomorphic evidence.*

*Estudios geoarqueológicos en la bajada sur de Sleeping Ute Mountain, ubicada en el suroeste de Colorado indica la presencia de corrientes efímeras descontinuos que fueron los centros de asentamiento periódicos desde d.c. 600s hasta d.c. 1280. Estos arroyos efímeros contienen bancos y barrancos, y son ideales para la forma de agricultura que utiliza agua de inundaciones, llamada ak chin. El abandono periódico de los pueblos en la bajada sur se correlaciona temporalmente con épocas de aridez, pero no corresponde a la erosión de los canales. No creemos que todas las sequías se correlacionan con erosión en toda la vertiente, y recomendamos cautela en el uso del modelo de sequía-arroyo como indicación de cambios en los asentamientos de sistemas fluviales sin datos apoyados por estratigrafía or geomorfología.*

One of the more vexing challenges facing archaeologists is explaining patterns of settlement shifts through time. This is particularly true for archaeologists working in the American Southwest where many diverse environments were occupied, abandoned, and reoccupied during the prehistoric era (Cordell et al. 1994; Fish et al. 1994). Explanations for regional and local level abandonment in the American Southwest include environmental, demographic, and behavioral factors (see for example Ahlstrom et al. 1995; Betancourt and Van Devender 1981; Cordell 1975; Dean 1988; Kohler 1992; Kohler and Mathews 1988; Lipe 1992, 1995; Upham 1984; Van West 1994). Because there are several excellent sources of paleoclimatic information in the Southwest, particularly tree-ring and pollen data, analysis of the impact of climatic change on prehistoric population movements in the Southwest has been a fruitful avenue of research (e.g., Dean et al. 1985; Euler et al. 1979; Petersen 1988).

This paper examines the impact of climatic change and arroyo cutting on prehistoric floodwater farmers in the northern Southwest. Floodwater farming was a widely-used agricultural strategy in the American Southwest and other arid regions throughout the world (Doolittle 1989). This strategy relies on periodic runoff or seasonal overbank flow in large streams to irrigate fields in areas where rainfall alone is insufficient to nurture crops. Floodwater farming played an important role in the subsistence strategies of many prehistoric groups in the Southwest. Although the Hohokam are well-known for their large riverine irrigation systems on the Salt, Gila, and Santa Cruz Rivers in southern and central Arizona, Hohokam groups living outside of these well-watered river valleys were largely dependent on floodwater farming (Fish et al. 1992; Masse 1991). In the northern Southwest, floodwater cultivation based on the diversion of ephemeral runoff onto fields through systems of ditches and dams supported large aggregated villages and small hamlets in Chaco Canyon that formed the center of the Chaco system (Sebastian

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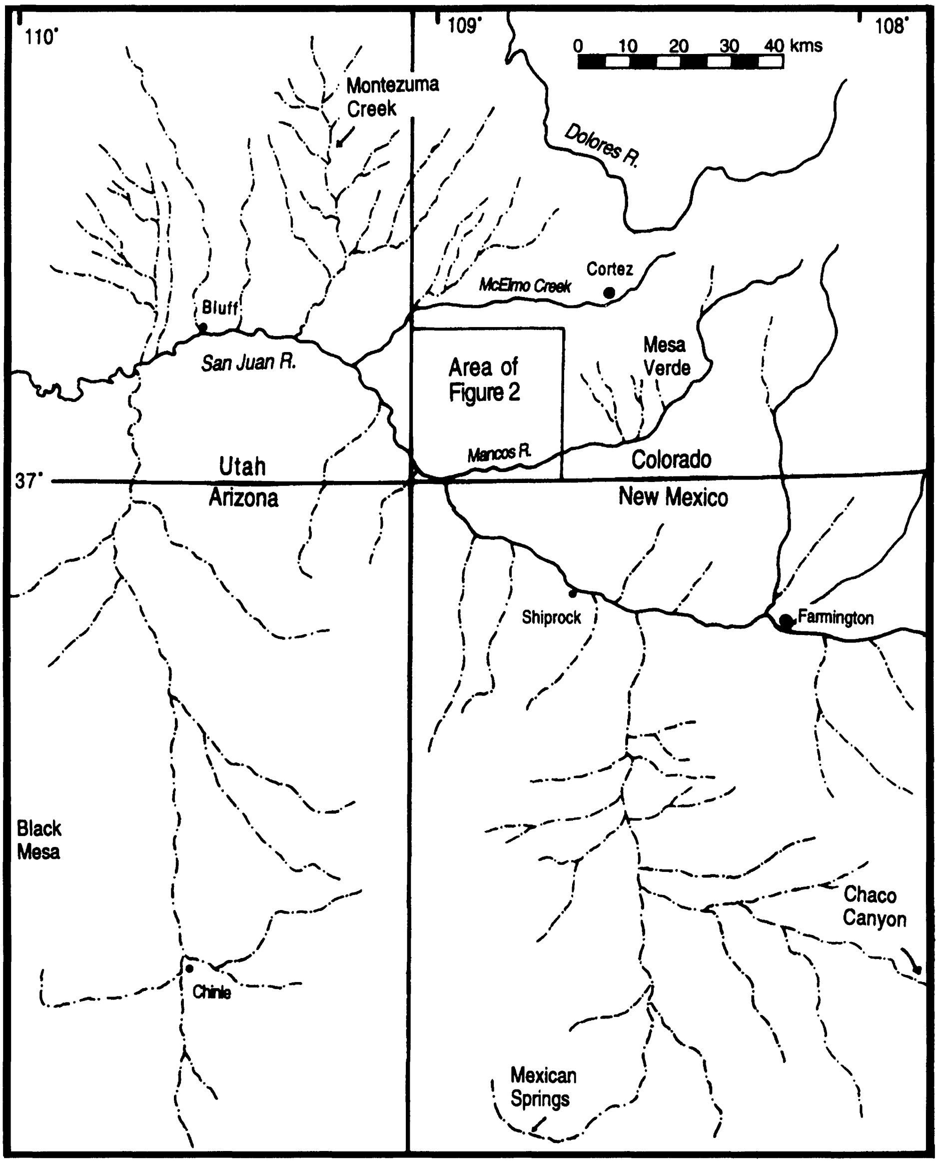


**Figure 1. Regional map of Four-Corners area and referenced stratigraphic study areas.**

1992:56; Vivian 1974, 1991). Consequently, understanding the dynamic relationships between floodwater farming and environmental change is important to understanding many of the larger issues of settlement growth and abandonment in the prehistoric American Southwest and in other arid regions.

One of the early ideas to come out of environmental archaeological research in the northern Southwest is that arroyo cutting in response to climatic change played an important role in prehistoric Puebloan settlement and abandonment. Quaternary geologist Kirk Bryan observed prehistoric arroyos containing artifacts in the cutbanks of modern arroyos and hypothesized that periodic stream entrenchment in alluvial valleys created problems for floodwater farming (Bryan 1929, 1941). When alluvial flood plains become entrenched, floodwaters are confined to channels and irrigable area is reduced. Because many Quaternary geologists working in the Southwest believe that arroyos were caused by drought and

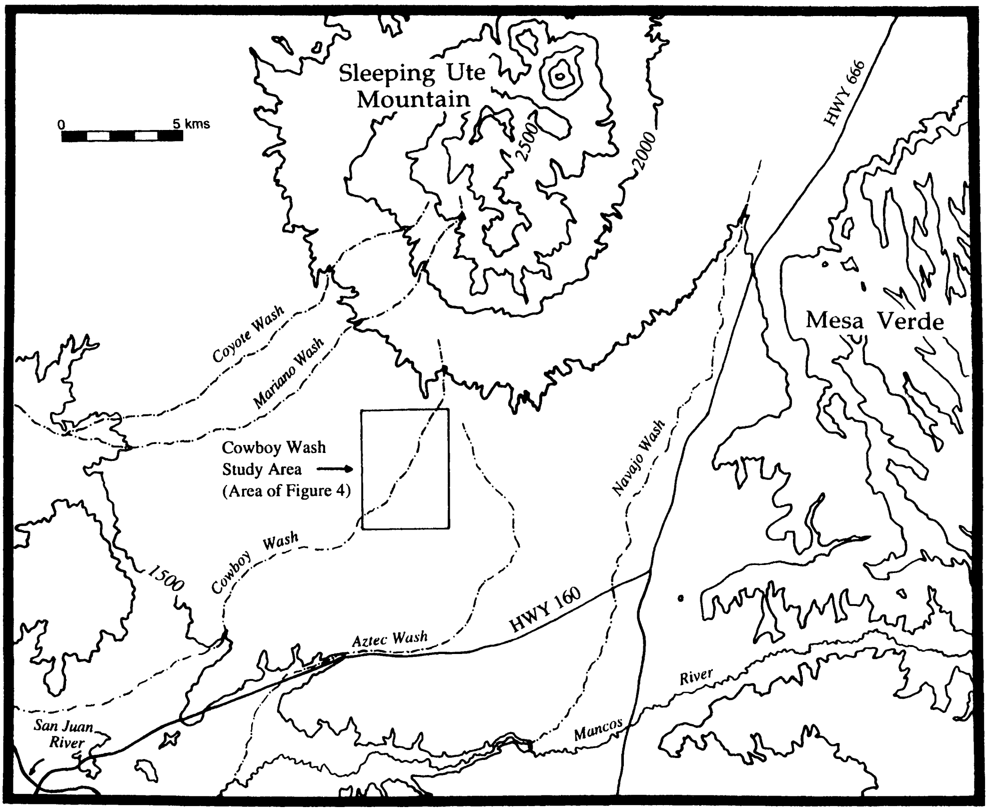


Figure 2. Map of southern piedmont of Sleeping Ute Mountain.

falling water tables (Antevs 1952; Bryan 1929; Haynes 1968; Karlstrom 1988), researchers have linked drought and erosion to local and regional Puebloan abandonment (Bryan 1954, Dean et al. 1985; Euler et al. 1979; Fuller 1988a; Hall 1977; Schlanger 1988). Links between climatic change and arroyo formation, however, are far from understood. Entrenchment may or may not be related to drought, because a multitude of factors, including channel slope, vegetation change, and human activity can cause erosion (Cooke and Reeves, 1976). Moreover, alluvial downcutting may not be continuous within a single watershed; if one segment of a fluvial system is eroding, the products of that erosion must be deposited somewhere else. If arroyos are discontinuous, periods of entrenchment may not necessarily have been as deleterious to floodwater agriculture, especially if population is well below carrying capacity (Dean 1988; Van West 1994).

The Ute Mountain Irrigated Lands Archaeological Project (UMUILAP) in extreme southwestern Colorado (Figures 1 and 2) provides an opportunity to test the drought-arroyo-abandonment model in an area that has experienced episodic Puebloan settlement and where a drought-arroyo mechanism for abandonment has been invoked (Fuller 1988a). Located on the southern piedmont of Sleeping Ute Mountain, the climate is generally too arid for dry farming, and it is assumed that the Anasazi relied mostly on floodwater farming on ephemeral streams for food production. Although opportunistic dry farming on ridgetops could have been feasible during extended wet periods, settlement on the southern piedmont represents a true dry land adaptation based on ephemeral stream flow. In this paper, we present settlement data for the southern piedmont and relate it to alluvial prehistory and modern arroyo behavior. We argue against drought-induced stream entrenchment as a driving force in episodic regional abandonment. The theme of this paper urges caution in invoking climatic-hydrological processes without local empirical evidence. We feel it may be inappropriate to temporally correlate abandonment to drought and assume that streams were downcutting during periods of reduced effective moisture. No two streams are alike, and each has to be treated individually.

### Climate Change and Stream Behavior

The debate over the effects of climate change and stream behavior is too extensive to address completely here[1]. Instead, a quick overview is presented as a context to the problem. Climate change and consequent stream behavior are analyzed at a variety of timescales ranging from long term (e.g., $10^3$ to $10^6$ years), to relatively short term (e.g., $10^1$ to $10^4$ years). Short-term channel behavior and links to climate change are often the focus of the "arroyo debate" (i.e., what mechanisms cause stream channels to incise their flood plains). Two main schools of thought exist regarding nonanthropogenic mechanisms that cause arroyos. One is that most episodes of erosion, whether cyclical or random, result from climate change and corresponding effects to vegetation and sediment yield. The other school emphasizes intrinsic adjustments in a fluvial system in response to changes in discharge, sediment load, and channel geometry that may or may not be driven by climate change.

In support of the climatic change view, climate undoubtedly affects the behavior of streams by influencing vegetation patterns, runoff, and sediment yield. Changes in the amount of runoff or sediment production within a watershed will impact channel geometry as the stream adjusts to accommodate new hydrologic conditions (Knighton 1984:162–189). Early in the debate was the question of whether or not arroyos were induced by a switch from dry to wet conditions (Huntington 1914) or vice versa (Antevs 1952; Bryan 1925a). Many stratigraphic studies conducted in the American Southwest provide good evidence that alluvial entrenchment corresponds in time to relatively dry periods as evidenced by calcic soils and dune activity (e.g., Bryan and Albritton 1943; Haynes 1968). Detailed alluvial stratigraphic work in the Black Mesa area by Thor Karlstrom and colleagues (Karlstrom 1988; Karlstrom and Karlstrom 1986) supports the Bryan-Antevs climatic model that drought, reduced vegetation, and lowered water tables result in valley entrenchment, at least in lowland settings on higher order streams. Dean et al. (1994) follow this model and explicitly associate periods of reduced effective moisture with flood plain degradation and consequent population shifts in the upland Southwest. In contrast, others look on an increase in rainfall intensity as being a key mechanism for valley incision (Balling and Wells 1990; Leopold 1951; Martin 1963). This is to say that changes in mean annual precipitation have less of an effect than increases in summer versus winter precipitation, the former associated with intense thunderstorms and the latter with cyclonic cold fronts and gentler rain and snowfall. Regardless of the specific climatic change responsible, those who favor a climatic mechanism as being responsible for arroyo formation emphasize regional correlations of alluvial sequences from distant areas (Haynes 1968).

Process-oriented studies that focus on climate change and arroyos emphasize the singular nature of fluvial systems and relationships between watershed geology, vegetation, precipitation, and sediment production. Fluctuating water tables do not induce erosion or deposition per se but, instead, are associated with changes in the water discharge:sediment load ratio that is the primary agent for channel change. For example, watersheds containing relatively easily eroded bedrock are more likely to respond (i.e., are more sensitive) to any given climate change (Bull 1991). In fact, differences in bedrock and soils between local catchment areas can result in different fluvial responses to the same climate change (McFadden and McAuliffe 1997). Watersheds also respond differently to a given climatic change depending on the vegetation they contain (Langbein and Schumm 1958). For example, increased precipitation in deserts will result in greater sediment runoff, whereas in more mesic environments (e.g., grasslands) more precipitation will result in less runoff or have little effect (Figure 3). Likewise, a decrease in precipitation can result in increased sediment yield in relatively mesic environments and a decrease in deserts. Although the curve in Figure 3 is empirically derived and not necessarily applicable to all fluvial systems, it demonstrates the non-monotonic relationship between precipitation change and sediment yield, and that droughts do not necessarily result in any one type of geomorphic response. All of these process-oriented

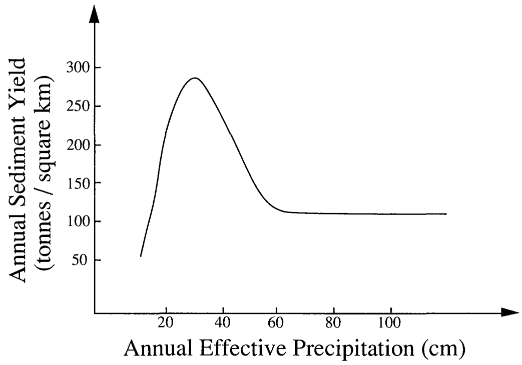


**Figure 3. Precipitation-sediment yield relationship for area with a mean annual temperature of 10° C (adapted from Langbein and Schumm 1958).**

studies highlight the regionality of geomorphic processes in the context of climate change.

That different environments and segments of a fluvial system respond differently to any type of climatic change has been the greatest challenge to arguments linking arroyos to drought. The second school of thought in the arroyo debate, represented by the work of Stan Schumm and his associates (Begin and Schumm 1984; Schumm 1977, 1991), emphasizes the singularity of landscapes and provides examples for nonclimatic mechanisms that can induce stream entrenchment. For example, entrenched reaches of ephemeral streams in Wyoming, Colorado, and New Mexico have been tied to nonclimatic factors such as oversteepened gradients due to discontinuous and episodic transport of sediment (Patton and Schumm 1981; Schumm and Hadley 1957; Wommack and Schumm 1977). Experimental flume studies have demonstrated that a single perturbation (e.g., a change in gradient or an increased pulse of sediment load) can result in numerous episodes of downcutting and filling that migrate up and down the watershed (Schumm and Parker 1973). In this view, disturbances such as drought or cattle grazing may result in both erosion and deposition in different places within a watershed. Proponents of this second school of thought are more likely to question causal correlations of arroyos and droughts and point out examples where valley fills do not correlate in time (e.g., Kottlowski et al. 1965; Waters 1991).

We feel both schools of thought have much to offer in Quaternary studies. Intrinsic geomorphic processes and physical differences between watersheds do not preclude a causative link between droughts and arroyos or correlative alluvial sequences in separate watersheds. They do, however, raise a cautionary flag: Each hydrological situation must be viewed as a unique entity that may or may not have climate-controlled, behavioral connections to other streams in the region. This is directly relevant to models of Anasazi abandonment that are tied to climate change and erosion, such as at Chaco Canyon (Bryan 1954; Hall 1977) and, more recently, in the Black Mesa region (Dean 1988; Dean et al. 1985; Euler et al. 1979; Karlstrom 1988). The Black Mesa cultural-paleoenvironmental model is based on multiple lines of empirical evidence from high- and low-order tributaries in the Little Colorado and Chinle drainage system, but how applicable it is to other areas in the Southwest has yet to be determined (Dean et al. 1985).

## Study Area

The project area of the UMUILAP is situated on a broad piedmont extending from Sleeping Ute Mountain to the San Juan River (Figure 2). Unlike much of the region, most of the southern piedmont is only moderately dissected, and is characterized by a suite of graded, relict pediments, and gentle slopes. This is attributable to the prevalence of Mancos shale, a relatively erodable, slope-forming unit (Ekren and Houser 1965). The larger ephemeral drainages on the southern piedmont from east to west are Navajo, Aztec, Cowboy, Mariano, and Coyote washes. The upper reaches of Cowboy, Mariano, and Coyote washes at the base of Sleeping Ute Mountain can support sustained flow along short reaches during the spring, but on the open piedmont they are generally dry throughout the year. On the piedmont, flood-plain widths vary from less than 100 m to more than 2 km and most are currently entrenched along their axial channels. This provides considerable exposure of Holocene stratigraphy that is characterized by tabular, sand, and finer textured alluvium formed through vertical accretion. Most of the piedmont soils are fine-textured with low permeability and developed into alluvium derived from shale. Exceptions are ribbons of sandy soils on ridge tops (Price et al. 1988) and the flood plains of the larger drainages that transport alluvium from the volcanic Sleeping Ute Mountain. The deepest and most agriculturally productive soils are in the flood plains of the large washes.

Project area elevations range 1500 m to 1800 m (4,900–5,900 ft) above sea level, and the area is warmer and dryer than the uplands to the north and east. Using Hovenweep National Monument as an example, mean annual precipitation is 29 cm, and there are approximately 145 frost-free days per year. Although the length of growing season is adequate for corn (i.e., more than 120 days as cited by Hack [1942]), in most years there is insufficient rainfall for dry farming, and some type of irrigation is necessary for reliable production of crops. Modern vegetation consists of low shrubs and is part of the Sonoran Great Basin desert shrub plant community (Lowe 1964), although juniper woodland extends to within one kilometer of the study area. Close proximity to uplands such as Sleeping Ute Mountain and Mesa Verde allows for quick access to a variety of plant and animal communities.

## Puebloan Settlement on the Southern Piedmont

As a result of archaeological investigations associated with the development of 7,600 acres of irrigated fields by the Farm and Ranch Enterprise of the Ute Mountain Ute Tribe, the early Puebloan occupation of the southern Ute Piedmont is well documented. Altogether more than 31,000 acres have been surveyed for proposed field areas (Fuller 1988a, 1989), upgrading the Aneth Road (Fuller 1984), and the construction of the Towaoc Canal (Walkenhorst and Hammack 1989). Survey has been concentrated in a broad band running east-west across the piedmont in the zone of highest agricultural potential and has resulted in the recording of over 270 prehistoric sites dating between the Early Archaic Period to late Pueblo III. In addition, numerous smaller surveys have been conducted elsewhere, all of which have been summarized in an inventory study (Errikson 1994). This extensive survey coverage is complemented by excavations conducted by Soil Systems, Inc., at 63 sites during the Ute Mountain Ute Irrigated Lands Archaeological Project (Billman 1997a, 1998). In addition, several other sites were excavated because of canal and lateral construction (Errikson 1994). In total, excavations have been conducted at 81 sites, 76 of them prehistoric.

### *Late Basketmaker III (A.D. 600–725)*

Although numerous Late Archaic Period sites have been recorded that date to the latter part of the last millennium B.C., no sites have been identified on the southern piedmont that date between 100 B.C. and A.D. 600 (Billman 1997a; Fuller 1988a, 1989). In contrast, 40 late Basketmaker III (A.D. 600–725) sites have been recorded. Survey reports describe 28 of these as habitation sites and 12 as low-density artifact scatters (Fuller 1984, 1988a, 1989). Survey data indicate that Basketmaker III habitation sites are scattered in a narrow band across the southern piedmont between 1,573 m (5,160 ft) and 1,659 m (5,440 ft) in elevation. All of these habitations are located close to large washes, from Coyote Wash to Navajo Wash, with more sites on Cowboy and Mariano washes. Habitation sites typically consist of a single pit structure depression, sometimes with an associated surface structure, seldom with any surface indications of middens or high-density artifact concentrations. Excavation data indicate that the sites appear to be the remains of seasonal habitations, occupied by small groups for only one or at the most a few seasons (Billman 1998; Errickson 1994:156–158, 276). Ethnobotanical data demonstrate that wild plants and maize were processed on the sites, a fact further confirmed by the presence of ground stone and large roasting areas. These characteristics are consistent with a summer use of the sites as small fieldhouses, which apparently were associated with nearby agricultural fields.

### *Pueblo I (A.D. 750–900)*

Sometime around A.D. 725, the seasonal, sporadic use of the piedmont ended. Out of the several hundred known prehistoric sites on the piedmont, less than 10 have Pueblo I components, and all of these components appear to be small artifact scatters. No Pueblo I components were found during the survey of fields, roads, and the Towaoc Canal (Fuller 1984, 1988a, 1989; Walkenhorst and Hammack 1989), an area of over 31,000 acres encompassing the prime agricultural zone on the piedmont. Excavations at 76 ceramic period sites resulted in the identification of only two Pueblo I components, which proved to be short-term camps with no structural remains (Billman 1998; Errikson 1994).

### *Middle-Late Pueblo II (A.D. 1050–1075)*

After a hiatus in occupation of approximately 300 years, sometime around A.D. 1050 a few habitation sites were occupied on the larger washes from

Navajo Wash to North Coyote Wash in a narrow band between 1,555 m (5,100 ft) and 1,665 m (5,460 ft) in elevation. A total of 32 habitation sites and 17 artifact scatters have been recorded on the southern piedmont that date between A.D. 1050 and A.D. 1075. Excavated habitations are remarkably similar in size, layout, architecture, and duration of occupation. All were generally small, consisting of one or two residential pitstructures, one small roomblock, and, in most cases, one semisubterranean mealing room. Unlike the Basketmaker III pit structures on the southern piedmont, the main residential pitstructures were large (12.5 $m^2$ to 19 $m^2$) and had large central hearths with ventilator systems and a full suite of domestic features including large storage pits and mealing bins. With few exceptions, no sites had any formal midden areas or dense accumulations of artifacts.

The middle-late Pueblo II occupation of the southern piedmont differed from the Basketmaker III occupation in that the establishment of year-round permanent residences was attempted. The presence of large interior hearths for cooking and heating and large storage facilities for foodstuffs is consistent with winter occupation. The location of the sites near arable land suitable for maize cultivation and the presence of numerous outdoor features and activity areas suggest summer use of the sites as well. Although considerable labor was invested in the construction of large deep residential pitstructures, semisubterranean mealing rooms, and roomblocks, the lack of trash accumulation and the absence of significant structure remodeling demonstrate that duration of occupation at most sites was relatively short. Based on the number of sherds, the duration of occupation at most of the excavated sites was probably only a few years. Unexcavated sites also seldom contain any discernible midden areas.

### *Late Pueblo II/Early Pueblo III (A.D. 1075–1125)*

The pattern of settlement on the southern piedmont changed dramatically around A.D. 1075. Habitation sites in the western part of the southern piedmont along North Coyote, Coyote, and Mariano washes were abandoned, and no habitation sites were established there until the historic era. In contrast to the dispersed occupation in Basketmaker III and middle-late Pueblo II, three communities were founded in this period, including one at Cowboy Wash.

The Cowboy Wash community consisted of a cluster of 16 habitation sites within an 8 $km^2$ area. Excavated sites had two to four large residential pitstructures, all of which had large central hearths, ventilator systems, southern recesses, large storage features and, in most cases, mealing bins. To the north of the pitstructures were one or more jacal or masonry surface structures with one to five rooms. Based on the interior features, these surface rooms were probably used for cooking, food processing, and storage. Sites also typically had one to three small subterranean mealing rooms with several slab-lined mealing bins. In contrast to previous occupations in the Puebloan period, all habitation sites have large dense middens containing tens of thousands of sherds.

Like the preceding middle-late Pueblo II (A.D. 1050–1075) habitation sites, these transitional Pueblo II-Pueblo III sites appear to represent year-round occupations. The presence of large interior hearths, ventilator systems, and storage features indicate that residents were wintering at these sites. Summer occupation is indicated by the presence of outdoor features and activity areas and the location of sites adjacent to arable land. The transitional Pueblo II-Pueblo III sites, however, differ in that the duration of occupation was probably one to two generations, typically 20 to 40 years as indicated by the quantities of trash and extensive remodeling of pitstructures. Unlike earlier examples, most pitstructures in this period contain hearth remodeling, sealed floor features, superimposed floors, and evidence of reroofing.

### *Early Pueblo III (A.D. 1125–1175)*

From A.D. 1125 to 1175, 11 habitation sites were occupied in the Cowboy Wash community within a 6 $km^2$ area. Of 16 habitation sites in use between A.D. 1075 and A.D. 1125, only one continued to be occupied. This discontinuity in occupation and the sharp increase in the frequency of Chuskan ceramic types suggest that the community may have been completely abandoned, and later reoccupied by a different group of people, possibly originating in the Chuska Mountains (Errikson 1994:497–498). Much as in the preceding time period, these habitation sites apparently were year-

Table 1. Summary of Settlement History at Cowboy Wash and Regional Environmental Conditions.

| Cowboy Wash Area | | | Regional Environmental Conditions (Dean et al., 1994) |
|---|---|---|---|
| A.D. 600–725 | BMIII; dispersed seasonal settlements | A.D. 400–750 | favorable; high effective moisture; flood-plain aggradation |
| A.D. 750–1050 | PI and early PII; abandonment | A.D. 750–925 | unfavorable; reduced effective moisture; flood-plain degradation |
| A.D. 1050–1075 | mid-PII; annual permanent settlements but short-lived | A.D. 1000–1275 | favorable; high effective moisture; flood-plain aggradation |
| A.D. 1075–1125 | PII-PIII transition; abandonment to the west; more permanent settlements | | |
| A.D. 1125–1175 | early PIII; reduced population; raiding; abandonment | | |
| A.D. 1175–1210 | abandoned | | |
| A.D. 1210–1280 | late PIII; consolidation at Cowboy Wash Pueblo; abandoned by A.D. 1280 | A.D. 1275–1450 | unfavorable; reduced effective moisture; flood-plain degredation |

round residences for one to three households for a single generation. Four of the 11 habitation sites in the early Pueblo III community have been excavated (Errikson 1994; Leonard et al. 1998). Pitstructures at all four excavated sites had disarticulated butchered human remains on their floors and appear to have been abandoned suddenly as a result of raiding (Billman 1997b; Lambert 1997; Leonard 1997).

### *Late Pueblo III (A.D. 1225–1280)*

By A.D. 1175, the southern piedmont was abandoned again until the early A.D. 1200s. At that time two new communities were founded on Cowboy Wash and Navajo Wash near Moqui Springs. The Cowboy Wash community has been completely surveyed (Fuller 1988a) and consists of 15 habitation sites situated within an 8 $km^2$ area. Cowboy Wash Pueblo, a large 100-room pueblo, is located 700 m north of the community and either post-dates the community or was contemporary with it. Excavations and testing at seven habitation sites in the Cowboy Wash community revealed that they were occupied year-round for one or two generations. By A.D. 1280, the southern piedmont was abandoned by Puebloan groups, and no subsequent prehistoric occupation has been detected.

### *Summary*

Archaeological investigations on the southern piedmont indicate that during the Puebloan period, there were five distinct occupations of the southern piedmont (Table 1). The two earliest occupations occurred between the early A.D. 600s and the early 700s (late Basketmaker III) and A.D. 1050 to A.D. 1075 (middle-late Pueblo II). Each of these two early occupations lasted no more than 100 years and were characterized by short, sporadic occupations. These two periods were separated by a 300-year occupational hiatus. The middle-late Pueblo II period of short-term occupation on the piedmont was followed by three periods of community formation between A.D. 1075 and 1125, A.D. 1125 and 1175, and A.D. 1210 and 1280, at which time the area was abandoned until the Historic era.

Changes in settlement patterns on the southern piedmont reflect larger-scale demographic patterns on the Colorado Plateau. The initial colonization of the southern piedmont by horticulturalists in Basketmaker III occurred during a period of regional population expansion and colonization of new areas (Dean et al., 1994; Dean et al. 1985; Euler 1988). Likewise, the virtual absence of sites on the piedmont in late Basketmaker III and Pueblo I (ca. A.D. 725 to A.D. 900) is consistent with a regional pattern of population movement to upland areas. Beginning in late Basketmaker III, populations in the Mesa Verde region migrated to large aggregated upland communities (Wilshusen 1991). Several CRM projects in the last 20 years have documented high-density Pueblo I occupations between 2,000 m (6,560 ft) and 2,200 m (7,380 ft) in elevation in the Dolores River Valley (Kane 1986), Ridges Basin (Fuller 1988b), Lewis Mesa (Chenault 1996), and Cedar Hill (Wilshusen 1995). These upland areas typically receive more precipitation but have a shorter growing season than lowland areas. This shift to upland areas has been linked to a period of warmer temperatures and longer growing seasons that permitted successful cultivation of these previously agriculturally marginal areas (Petersen 1988; Schlanger 1988).

The second attempt at colonization of the southern piedmont in middle-late Pueblo II (ca. A.D. 1050) occurred in a period of dramatic population expansion and dispersal on the Colorado Plateau (Dean et al., 1994; Euler 1988). With the exception of the upland areas occupied in Pueblo I, population peaked in many areas of the Colorado Plateau between A.D. 1050 and A.D. 1150. The subsequent abandonment of the southern piedmont in early Pueblo III correlates to a period of regional population redistribution with abandonment of numerous areas, most notably Black Mesa, Grand Canyon, the Virgin River, and Chaco Canyon. The final occupation and abandonment of the southern piedmont by Puebloan groups in Late Pueblo III (A.D. 1210 to A.D. 1280) corresponds to a period of renewed population growth in the early A.D. 1200s, population aggregation in the middle A.D. 1200s, and depopulation of the Mesa Verde region in the late A.D. 1200s (Adler et al. 1996; Dean et al., 1994; Lipe 1992, 1995; Schlanger 1988).

## Alluvial Geology and Discontinuous Ephemeral Streams

Fuller (1988a) noted that occupation of the southern piedmont during Basketmaker III and late Pueblo II-early Pueblo III periods corresponds to relatively moist and/or cool conditions, whereas episodes of abandonment during Pueblo I and late Pueblo III periods correspond to periods of warmth and less effective moisture (Burns 1983; Euler et al. 1979; Petersen 1988). Following the paleoenvironmental model of the Black Mesa area (Euler et al., 1979), Fuller hypothesized that arroyos formed on the southern piedmont during these dry periods and helped force the population to upland areas. Likewise, with resumption of relatively moist conditions, streams aggraded, creating situations favorable for floodwater farming, and people returned. To assess the nature of arroyo formation on the southern piedmont and to test if arroyos formed during these periods of aridity and settlement abandonment, geological investigations were performed during the UMUILAP (Huckleberry 1998).

Reconnaissance of the axial channels of Aztec, Cowboy, Mariano, and Coyote washes on the middle and upper parts of the piedmont revealed that the flood plains are composed mostly of fine-textured, silty, and fine sandy alluvium. Gravelly alluvium is limited to floors of the modern incised axial channels and small, discontinuous lenses exposed in arroyo walls. A paucity of cut-and-fill channel sequences suggests that most deposits were formed by overbank increments of sediment. Pale brown (10YR) color and weakly developed soils further suggests that most of the exposed alluvium is late Holocene in age. An exception is Cowboy Wash, the only drainage on the piedmont where buried arroyos and mature soils were identified. The catchment area for Cowboy Wash is 130 $km^2$, similar to the small-to-intermediate-sized (50 $km^2$ to 100 $km^2$) hydrologic basins on the Colorado Plateau that contain streams with maximum stream power (Graf et al. 1987:264). Maximum stream power, defined here as the stream's ability to transport sediment (Bull 1991:13), facilitates high-frequency dynamics of stream entrenchment and backfilling. The Cowboy Wash flood plain also contains a relatively high concentration of Puebloan sites (Figure 4). Consequently, Cowboy Wash became the focus of our stratigraphic analysis.

An alluvial chronology for Cowboy Wash was constructed using soil stratigraphy, archaeology, and $^{14}C$-dated alluvial charcoal (Figure 5). Although there are problems associated with $^{14}C$ dates on alluvial detrital charcoal, particularly that old wood can generate ages older than the date of deposition (Dean 1988:129; Schiffer 1986), alluvial chronologies in the Southwest are typically based on $^{14}C$, and less commonly on tree rings or tree-ring calibrated ceramics. Stratigraphic data were collected from a 3-km segment of the Cowboy Wash flood plain (Figure 4), the only segment where buried arroyos were identified. Most of the exposed alluvium is younger than 5,000 years. Pleistocene alluvium capped by a red clay-enriched paleosol is exposed in only one reach of Cowboy Wash at a depth of 5 m at Stratigraphic Locality 2. A paleochannel there filled with organic silty clay is incised into the late Pleistocene soil and contains charcoal near its base that yielded a $^{14}C$ age of 3670 ± 80 years BP (B.C. 2280–1870 and B.C. 1830–1780)(Table 2).

Of greater significance to Puebloan prehistory, a younger paleochannel with gravelly sandy fill was identified at Stratigraphic Locality 1. Alluvial detrital charcoal from the upper part of the channel

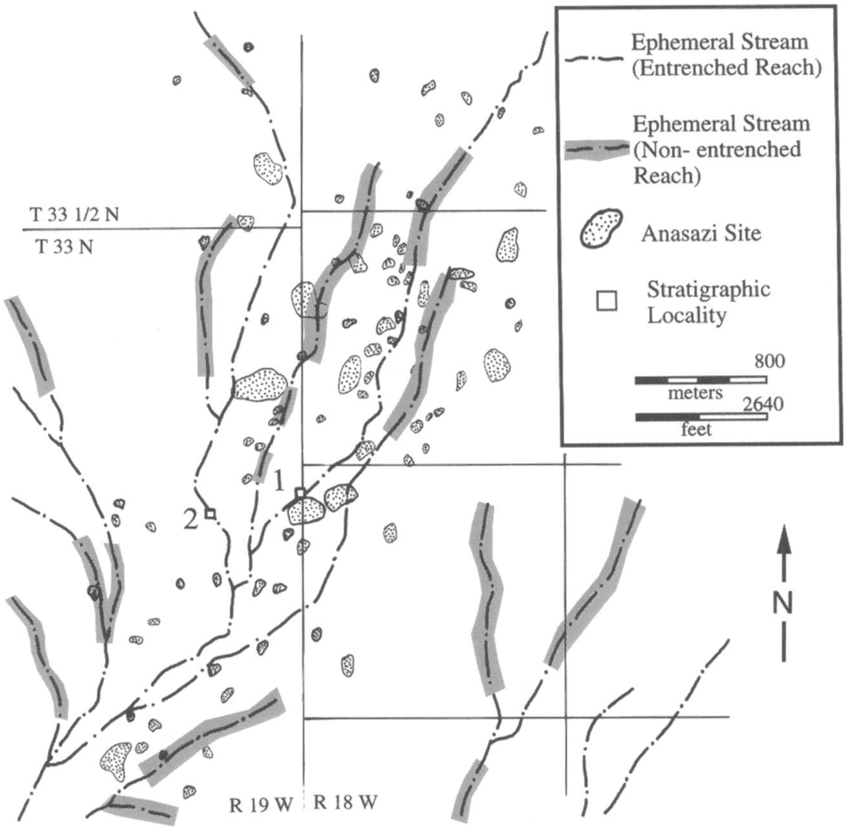


**Figure 4. Map of Cowboy Wash stratigraphic study area.**

yielded ages of 970 + 50 $^{14}$C years BP (A.D. 950 to A.D. 1195) and 680 ± 50 $^{14}$C years BP (A.D. 1265 to A.D. 1400). The younger sample is deeper in the subsurface but contained within a later inset channel, indicating that the channel downcut and backfilled twice. When this arroyo formed is important to understanding how much of an effect flood-plain entrenchment had on human abandonment of Cowboy Wash. Because $^{14}$C ages come from the middle to upper part of the fill, we can

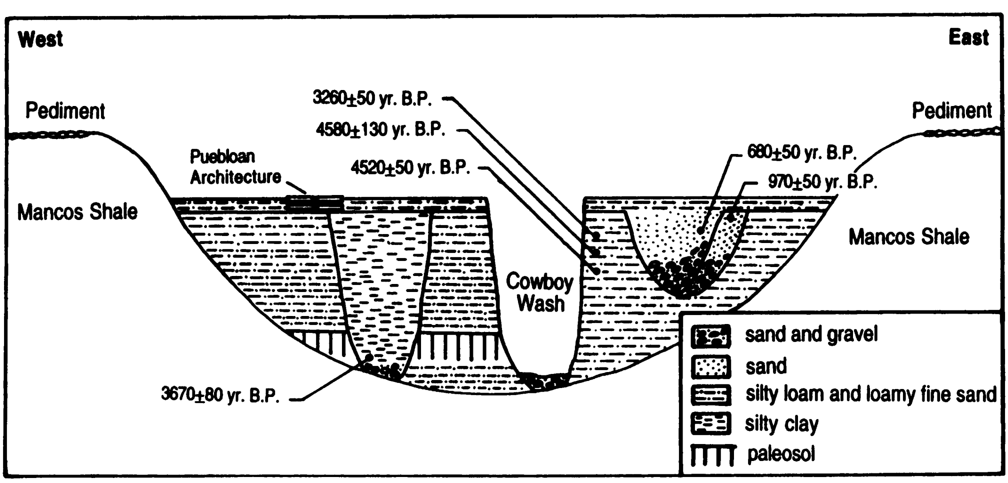


**Figure 5. Generalized composite geologic cross-section of Cowboy Wash (not to scale).**

Table 2. Radiocarbon Ages from Cowboy Wash Flood Plain.

| Location | Material Dated | Beta Number[a] | Conventional Age | $^{13}C/^{12}C$ Ratio ($^{13}C$) | Calibrated Age[b] |
|---|---|---|---|---|---|
| Site 5MT9541 | alluvial, detrital, charred material | 85818 | 4580 + 130 | -22.4 | B.C. 3645–2910 |
| Site 5MT9933 | alluvial, detrital, charred material | 85814 | 3260 + 50 | -17.2 | B.C. 1645–1420 |
| Site 5MT9933 | alluvial, detrital, charred material | 85817 | 4520 + 50 | -8.1 | B.C. 3360–3035 |
| Stratigraphic Locality 1 | alluvial, detrital, charred material | 85815 | 680 + 50 | -20.6 | A.D. 1265–1400 |
| Stratigraphic Locality 1 | alluvial, detrital, charred material | 85816 | 970 + 50 | -11.2 | A.D. 990–1195 |
| Stratigraphic Locality 2 | alluvial, detrital, charred material | 85819 | 3670 + 80 | -11.5 | B.C. 2280–1870 and B.C. 1830–1780 |

[a]Beta-85814, -85815, -85816, and -85817 were analyzed with accelerator mass spectrometry; Beta-85818 and -85819 were analyzed with conventional radiometric counting.
[b]2 sigma, 95 percent probability; see Stuiver et al., 1993.

only infer that the flood plain entrenched prior to A.D. 950 and backfilled sometime between A.D. 1265 and A.D. 1400, or soon thereafter. Because late-Holocene cutting and backfilling of channels in the Four-Corners region typically occurs at time scales of 550 years or less (e.g., Agenbroad 1975; Karlstrom 1988) and in some cases as rapidly as 100 years (e.g., Christensen 1985; Love 1979), we believe that it is very likely that entrenchment began after A.D. 400 (Figure 6). It is possible that valley entrenchment was initiated during Pueblo I time as hypothesized by Fuller (1988a), and that arroyo formation contributed to human abandonment during that time. If, however, arroyos pushed

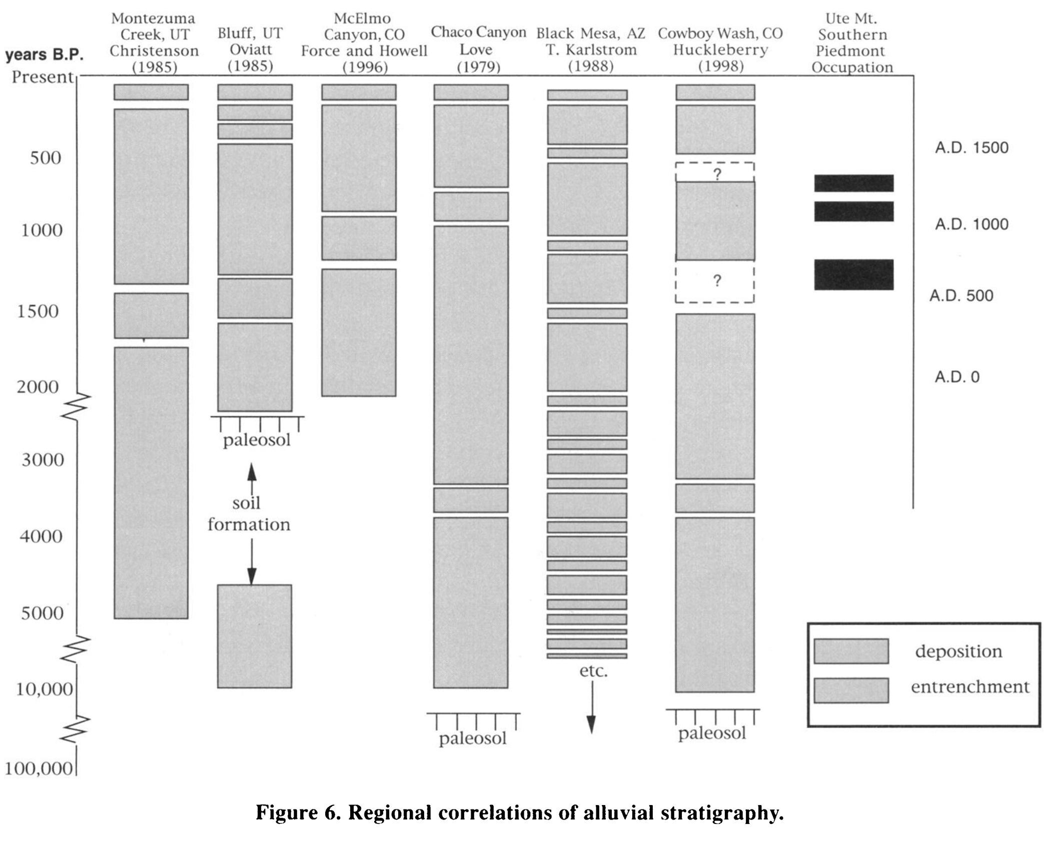


**Figure 6. Regional correlations of alluvial stratigraphy.**

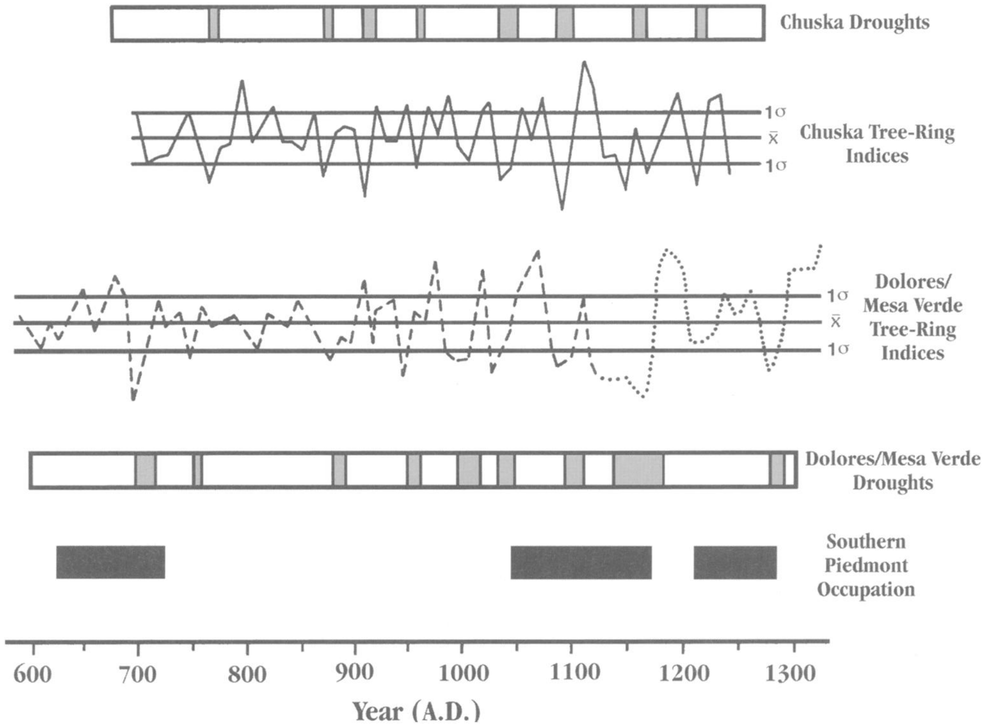


**Figure 7. Tree-ring indices and drought intervals for the the 4-Corners Area with intervals of human occupation on the southern piedmont (adapted from Fuller 1998a: Figure 32 and Petersen 1986: Figure 4.19).**

people out in Pueblo I time, people nonetheless returned later to Cowboy Wash in Pueblo II and Pueblo III time while the flood plain was still partly entrenched. There is no evidence of a renewed cycle of arroyo formation in the A.D. 1300s during the final abandonment of Cowboy Wash and the Mesa Verde region.

Whether or not drought played a role in arroyo formation at Cowboy Wash requires a consideration of regional paleoclimatic and stratigraphic data. The tree-ring record provides insight into variations in precipitation on the southern piedmont during the Puebloan period and can be compared to the alluvial chronology. Eight or nine episodes of drought of irregular frequency and duration occurred between A.D. 600 and A.D. 1300 based on tree-ring series from the Mesa Verde area (Burns 1983; Fuller 1988a; Petersen 1986:Figure 4.19; Figure 7). Several moist and dry intervals are associated with the period coeval with the Puebloan arroyo prior and episodes of human settlement along Cowboy Wash. As is commonly seen when comparing geological and tree-ring records, wet and dry intervals tend to occur at a higher frequency than cycles of downcutting and backfilling when the latter is defined by radiocarbon methods (Dean 1988:146–164). Without greater age control on Cowboy Wash alluvial stratigraphy, it is unclear if any of these droughts were catalysts for arroyo formation or subsequent backfilling on the southern piedmont.

Evidence of regional synchroneity in arroyo formation would favor a climatic mechanism for valley entrenchment. Indeed, there are aspects of the alluvial chronology at Cowboy Wash that correlate to other areas in the region (Figure 6), including Black Mesa (Hack 1942; Karlstrom 1988), Mexican Springs on the southeastern slope of the Chuska Mountains (Huckleberry 1989; Leopold and Snyder 1951), and Chaco Canyon (Hall 1977; Love 1979) (Figure 1). The Cowboy Wash sequence is very similar to Chaco Canyon in that each contains a Pleistocene paleosol and buried arroyos dating to approximately 2300 B.C. and A.D. 1100–1200 (Love 1979), although Chaco Canyon also has other undated, late-Holocene buried arroyos (Love 1983). Also, many drainages including Cowboy Wash experienced flood-plain degradation during Anasazi time. However, there also are discrepancies in the

Table 3. Entrenched Cumulative Stream Length Measurements.

| Stream | Study reach elevation above sea level (m) | Cumulative stream length (km) | Percent entrenched axial stream length | Cumulative total stream length (km) | Percent entrenched total stream length |
|---|---|---|---|---|---|
| Aztec Wash | 1610–1720 | 6.4 | 89.5 | 47.8 | 50.1 |
| Cowboy Wash | 1592–1735 | 7.9 | 100.0 | 32.6 | 62.2 |
| Mariano Wash | 1504–1714 | 11.7 | 89.5 | 29.7 | 69.0 |
| Coyote Wash | 1507–1705 | 10.5 | 95.4 | 95.4 | 52.3 |

alluvial histories of the different stream systems. For example, at Montezuma Creek, a tributary to the San Juan River located 50 km to the northwest, entrenchment occurred prior to A.D. 500 (Christensen 1985). A brief period of entrenchment also occurred around A.D. 500 on tributaries to the San Juan River near Bluff, Utah (Oviatt 1985), 45 km downstream from the project area. Both of these episodes of stream incision appear to predate the Puebloan paleochannel at Cowboy Wash. On the north side of Sleeping Ute Mountain along McElmo Creek (Figure 1), entrenchment also occurred relatively early, around A.D. 700, and continued to about A.D. 1000 (Force and Howell 1996). This paleochannel partly coincides in time with that on Cowboy Wash, but the arroyo on Cowboy Wash persisted later into the thirteenth century.

In sum, although there are similarities in the alluvial histories of different stream systems, the timing of arroyo formation in the Four-Corners region varies. Perhaps this is not surprising, given the contrasting size and geology of the different watersheds considered (McFadden and McAuliffe 1997; Waters 1991). Many of these studies are based on stream channels with hydrologic basins that vary 10 times or more in area. For example, Karlstrom's (1988) hydrologic model for the Black Mesa area is derived largely from data collected along valley floors and recognizes asynchronous behavior between high- and low-order streams. Also, there are climatic differences along altitudinal and longitudinal scales in the 4-Corners region (e.g., the predominance of summer monsoon moisture diminishes westward). Clearly, it is difficult to control for these variables when comparing different watersheds. Given only the $^{14}$C-dated stratigraphy at Cowboy Wash, we cannot disprove a drought mechanism in arroyo formation. However, a broader look at the age of regional paleochannels suggests that factors other than drought are responsible. Such nonsynchroneity between alluvial chronologies in the Four-Corners region does not preclude the effect of climate, but it does point to more local mechanisms affecting arroyo downcutting and backfilling.

In an attempt to better understand channel cutting and filling on the southern piedmont, modern channel characteristics also were studied. This approach assumes that the present stream channels are reasonable analogs for prehistoric channels which may be questionable given considerable land-use changes within the watershed over the last 100 years—the most notable being cattle grazing. However, we believe that historic land-use changes have probably accentuated degradational processes in the upper watershed but have not altered the basic fluvial operation of the system. That is, these washes may be more entrenched today than during any previous time, but fundamental characteristics such as discontinuous entrenchment, are persistent despite anthropogenic disturbances.

Modern channels in Aztec, Cowboy, Mariano, and Coyote washes on the upper piedmont were studied in detail. In addition to field reconnaissance, longitudinal profiles and cumulative lengths of entrenched and nonentrenched reaches of the main flow channel and tributaries were measured from aerial photography and topographic maps with a map wheel. Although arbitrarily defined, only tributaries marked on U.S. Geological Survey 7.5-minute topographic maps with the stream symbol were considered. These measurements confirm that most main trunk channels are incised (Table 3), but, for most of these streams, entrenchment is not continuous. Aztec, Mariano, and Coyote washes have short segments where the main channel is not incised and distributary flow patterns indicate present aggradation. This constitutes less than 11 percent of the total length of the axial stream channel for Aztec and Mariano Washes and less than 5 percent for Coyote Wash; only Cowboy Wash has a main trunk stream that is continuously entrenched. However, if tributaries are included with the main

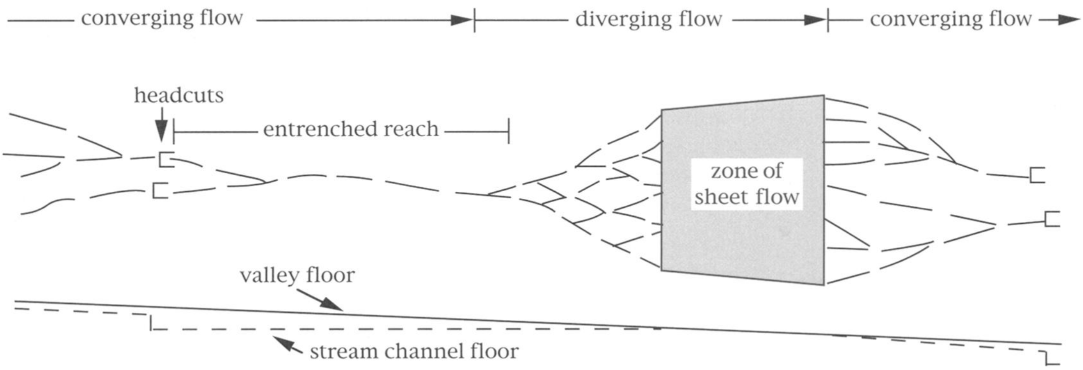


**Figure 8. Schematic plan view and profile of a discontinuous ephemeral stream (adapted from Packard 1974).**

axial streams, less of the drainage net is degrading: only 50, 52, 62 and 69 percent of the Aztec, Coyote, Cowboy, and Mariano total stream lengths are incised, respectively. Hence, despite significant ongoing erosion, three out of the four main washes in the watershed have reaches on the main channel that ostensibly could be utilized for floodwater irrigation today, as well as most of the tributaries for all four drainages.

That many arroyos on the southern piedmont are discontinuous indicates that erosion is not uniform and that there are alternating reaches of erosion and deposition. Such channel configurations have been recognized in other arid to semiarid locations where valley gradients are low and valley fill is fine-textured (Bull 1997; Huckleberry 1993; Packard 1974; Schumm and Hadley 1957; Waters 1991; Waters and Field 1986). In the Four-Corners region, discontinuous arroyos have been recognized at the Chaco Canyon (Bryan 1954) and Hopi Mesas area (Thornthwaite et al. 1942). In the study area, stream gradients are not particularly low, but the textures of valley floor sediments are fine due to their primary parent material, Mancos Shale. Packard (1974) named this type of watercourse a "discontinuous ephemeral stream." Like braided and meandering streams, discontinuous ephemeral streams have a distinct planform with different components (Waters and Field 1986; Figure 8). The sequence consists of stream segments that alternately concentrate and disperse stream flow within a series of entrenched and nonentrenched reaches. The entrenched reach begins with a single headcut or series of headcuts that capture shallow channel flow that subsequently becomes consolidated into one or a few deep channels. The bottoms of the incised channels have downstream gradients less than that of the valley floor, so that the channels become progressively more shallow downstream. Eventually, the channel bottoms and valley floor intersect where flow in the non-entrenched channel becomes less confined and channel geometry converts from a few, relatively deep channels to numerous, shallow distributary channels. Eventually, the numerous tributary channels lose their form, and flow becomes completely unconfined in a zone of sheet flow. Downstream sheet flow consolidates again into shallow channels, forming a dendritic pattern. This flow eventually leads to a headcut and the sequence is repeated.

An important aspect of discontinuous ephemeral streams is that they are spatially dynamic with different reaches of the system migrating upstream through time. Stream power is maximum in the entrenched reach but decreases as the channel becomes shallower. As channel depth reduces and flow becomes distributed into several channels, the hydraulic radius decreases and the hydraulic roughness increases. This reduces stream power, which leads to deposition of sediment forming broad alluvial fans within the channel or "channel fans." Sedimentation on the channel fans impedes flow and diverts the water laterally across the flood plain. This was observed during a thunderstorm in July 1996 where runoff was diverted away from the incised main channel of Cowboy Wash upstream from the project area near an entrenched (abandoned) cattle tank. This resulted in a broad zone of sheet flow on the flood plain, while the main trunk channel remained dry. As sediments accumulate, the gradient immediately upslope from the channel fans decreases whereas the gradient immediately downslope increases. Eventually, a headcut develops downslope from the channel fans because of the increased gradient, and both the channel fans and headcuts migrate upstream. These channel dynamics represent an energy-efficient method of moving sediment by increasing the hydraulic gradient within over-steepened, aggradational reaches (Schumm and Hadley 1957).

## Discussion

Regional and local data on arroyo cutting illustrate two important points. First, alluvial chronologies for various streams in the Four-Corners region (Figure 6) reveal an imperfect pattern of synchronous aggradation and degradation. Downcutting can be temporally correlated between some valleys but not in others, suggesting that there is no simple correlation between climate and cycles of erosion and deposition. Hydrological systems are complex, and given the variables that influence discharge and sediment yield, different fluvial systems can be expected to respond differently to climate change or other perturbations. It is uncertain what impact late Holocene climate change had on arroyo activity on the southern piedmont, although it is reasonable to assume that the erodable nature of Mancos Shale makes these drainages sensitive to changes in precipitation as well as increased grazing pressure. Nonetheless, climate change need not be invoked for downcutting and backfilling; streams in small catchment areas may contain a suite of valley deposits that are produced and eroded as a product of internal adjustments (Wommack and Schumm 1977). Distinguishing between climatic change and intrinsic geomorphic adjustments as mechanisms for periodic entrenchment of the southern piedmont alluvial valleys is difficult at best.

The second point illustrated by regional and local data is that studies of alluviation and local abandonment must take into account local stream geometry. If the modern streams of the southern piedmont are a good analogy, arroyos were probably discontinuous within the stream network during the Puebloan period. Segments characterized by deep arroyos that alternated with aggrading, channel fan reaches, and segments of deposition and erosion, likely shifted at decadal time scales. Radiocarbon dating has a limited time resolution that precludes defining the time-transgressive nature of such cutting and filling. In contrast, Force and Howell (1996) utilized tree-ring-dated ceramics to recognize a time-transgressive arroyo during Basketmaker III and Pueblo I time on McElmo Creek. They noted that this episode of entrenchment would not have been disruptive to agriculturalists given that field areas could be moved up or downstream to aggrading reaches. Although downcutting and backfilling of streams has been viewed as a type of low-frequency environmental variability (Dean 1988; Dean et al. 1994), in the context of discontinuous ephemeral streams, they are high-frequency events occurring at human time scales.

Today, much of the Cowboy Wash flood plain is entrenched, but overbank floodwater farming is still possible because unentrenched channels are also present. Water can be diverted out of the unentrenched segments of the mainstream onto land adjacent to entrenched segments—a situation that occurred during a 1996 thunderstorm. If stream entrenchment did reduce the amount of land irrigable by overbank floodwater farming during the Puebloan period, the impact on agriculture could have been minimized by a switching to an alternative form of water delivery. Other types of floodwater farming are well suited for arroyos (Doolittle 1989), especially if they are discontinuous (Waters and Field 1986; Waters 1991). A common type of floodwater farming in drylands is *ak chin*, a Tohono O'odham word for "arroyo mouth" (Bryan 1925b; Nabhan 1986). It is characterized by the placement of agricultural fields below confined reaches of ephemeral streams where water spreads laterally into a broad zone of sheetflow. Historic and prehistoric *ak chin* systems in the Southwest have been documented in the arid lowland deserts (Bryan 1925b; Castetter and Bell 1942; Masse 1991) and the semiarid upland plateaus (Hack 1942; Vivian 1991). In the lowland deserts of the basin and range country, *ak chin* agricultural systems are typically associated with large alluvial fan complexes or bajadas (e.g., Fish et al. 1992; Waters and Field 1986). In the upland plateau country, they are more commonly associated with smaller channel fan systems confined by bedrock (e.g., Hack 1942; Thornthwaite et al. 1942:Figure 55). On the southern piedmont of Sleeping Ute Mountain, *ak chin* systems are relatively small and associated with channel fans located in the narrow sandy alluvial valleys inset into shale bedrock. Regardless of size, *ak chin* farming is a highly refined form of human adaptation to environments generally considered unfavorable for agriculture. It also is a sustainable form of food production because of repeated application of nutrients and sediments to field areas with each flood (Nabhan 1986).

Given the hydrology and geomorphology of the southern piedmont, both overbank floodwater and ak chin farming could have been practiced when flood plains remained nonentrenched; overbank floodwater irrigation could be employed along the main axial channels and *ak chin* along the mouths of the tributaries. When entrenchment reduced the amount of irrigable land along main axial streams, emphasis would have shifted to *ak chin* farming along the short nonentrenched segments of the axial channels and the smaller tributary streams. Tributaries within Chaco Canyon were utilized for irrigation (Vivian, 1974), probably when the main axial channel was entrenched (Love 1979, 1983). Earlier this century, the Hopi made the switch from main trunk streams to smaller tributaries for floodwater irrigation (Hack 1942), and it appears that the Tohono O'odham likewise shifted their fields to smaller ephemeral streams in response to historic arroyo cutting (Fish et al. 1992; Nabhan 1986). In the case of the Hopi, a greater number of smaller fields were placed along the nonentrenched portions of smaller tributaries at the mouth of the upstream arroyo. This resulted in settlement shifts [see Bradfield (1971) in Waters (1992:5–6)], but did not lead to abandonment.

This strategy of shifting fields to nonentrenched reaches is indicated by the settlement pattern data from Cowboy Wash. During the two periods of community formation in late Pueblo II/early Pueblo III and late Pueblo III, year-round habitation sites were clustered near the center of the flood plain. However, small artifact scatters are distributed across the entire flood plain. These small sites do not contain structural remains and probably represent the remains of small field camps associated with adjacent fields. Because the overall size of the flood plain was relatively small, any potential field location would have been a short walk from a habitation site near the center of the flood plain. Small field camps were probably used during the day for cooking and maintenance activities during cultivation, tending, and harvesting of the fields. Shifting of fields created a dispersed scatter of these field camps up and down the main trunk of the stream on smaller branches, while the locations of habitation sites remained static.

The minimum catchment area necessary for supporting a field of crops on the southern piedmont is unknown and depends on basin geometry, soil characteristics, and rainfall. At the Hopi Mesas, Hack (1942) noted that the ratio of field size to supplying watershed area ranged from .03 to .06, depending on watershed characteristics. Larger fields per unit catchment area could be supported on watersheds with bare shale slopes that generate greater runoff, provided that the agricultural field soils at the mouth of the catchment area were more permeable. The smallest catchment area used for ak chin farming noted by Hack was 93 ha (230 acres). Many of the tributaries to the main washes on the southern piedmont of Sleeping Ute Mountain exceed this area and drain fine-textured soils with low permeability. These tributaries could support small agricultural fields given near average rainfall. Modern observations of summer runoff show that these tributaries often support discharge, while the main channels, with deeper, more permeable soils, are dry. Moreover, junctions of tributaries and flood plains of the main washes would be ideal for field placement, given the combination of deep sandy soils receiving runoff from watersheds with relatively impermeable, clayey soils.

The presence of discontinuous ephemeral streams on the southern piedmont may explain why there is such an apparent absence of water control structures (Fuller 1988a). Environmental constraints indicate that some type of floodwater irrigation is necessary here, but archaeological evidence of rock alignments or earthen berms is lacking. However, the very nature of discontinuous ephemeral streams makes them ideal for ak chin farming (Waters and Field 1986). Stream flow is naturally concentrated along incised reaches and then spreads laterally at the channel fan. The channel fan, composed of distributary channels and zones of sheet flow, is where crops would be planted. Thus, the channel geometry minimizes the labor required to control and divert the water, as might be necessary on main trunk streams lacking distributary drainage patterns. Agricultural fields can be moved in tandem with shifting zones of channel entrenchment and fan deposition. Because much of the work of water control is performed by the stream channel, there is less need to construct rock or earth alignments. Labor-intensive water control devices can be associated with *ak chin* irrigation (Masse 1991; Nabhan 1986; Vivian 1974), but are not necessary if channel geometry is favorable for water delivery to areas in a way that limits erosion or excessive deposition (Bryan 1929). Many water control features that are used to divert streamflow tend to be highly ephemeral structures made of brush, rock, and earth (Bryan 1925b; Castetter and Bell 1942; Doolittle 1984; Fish et al. 1992; Nabhan 1986) and have a low probability of preservation in the archaeological record.

If arroyo cutting did not play a role in the abandonment of the southern piedmont of Ute Mountain, what factors were responsible for the episodic abandonment of the area? Settlement pattern studies of Chaco Canyon (Hayes et al. 1991) and the Tucson Basin (Fish et al. 1992) clearly demonstrate that prehistoric floodwater cultivation in the Southwest was capable of sustaining relatively large populations for long periods of time. Why some areas were able to sustain long-term occupations, while the southern piedmont did not, may be related to the relatively small watersheds of the washes on the southern piedmont. For instance, the total watershed above the area of prehistoric cultivation (1,676 m or 5,500 ft) for Cowboy Wash and the other major washes on the southern piedmont is only 1,825 ha (4510 ac) or less (Fuller 1989:12). Although small catchment areas could support ak chin agriculture, overall food production through floodwater farming may have been more vulnerable to extended droughts because of the relatively small size of these watersheds.

The marginal nature of prehistoric agriculture on the piedmont is confirmed by studies of Puebloan human remains from the piedmont (Lambert 1998), which indicate extremely poor health and nutrition, even relative to other marginal areas in the northern southwest, such as Black Mesa. The human remains also indicate high levels of violence and trauma relative to other prehistoric burial populations in the northern Southwest, which points to considerable social stress and conflict during the Puebloan occupation (Lambert 1997). The small watersheds, poor health of Puebloan groups, and relatively high levels of violence suggest that prehistoric horticulture was sustainable on the piedmont only during periods of high precipitation, and that even in the best of times horticulture was difficult. Consequently, decreased precipitation probably was a crucial factor influencing abandonment of the piedmont.

Social factors should not be overlooked when examining episodic abandonment on the piedmont and elsewhere in the Southwest. Coupled with the marginal nature of the piedmont, the push and pull of other communities in the region may have induced periods of abandonment. During the 300-year occupational hiatus between A.D. 725 and A.D. 1025, the formation of large, aggregated communities in upland areas in the Mesa Verde region during Pueblo I and subsequently in Chaco Canyon may have exerted considerable pull, drawing people away from the piedmont and other marginal areas. Periods of apparent increased raiding and violence, such as in the mid to late A.D. 1100s (Billman 1997b) and the late A.D. 1200s (Haas and Creamer 1993; Lightfoot and Kuckelman 1995), also may have forced the abandonment of the piedmont. The presence of disarticulated, butchered human remains on the floors of residential pitstructures in the Cowboy Wash community dating to Early Pueblo III strongly suggest that raiding and violence coupled with drought caused the abandonment of the piedmont between A.D. 1175 and the early 1200s (Billman 1997b). The Mesa Verde tree-ring sequence (Figure 7) indicates that the period from A.D. 1150 to A.D. 1190 was one of the severest droughts in the region in the Puebloan era (Fritz et al. 1965:117–120; Petersen 1985:Figure 4.19).

## Conclusions

Puebloan settlements on the southern piedmont of Sleeping Ute Mountain represent periodic attempts at horticulture that rely heavily on floodwater irrigation. From the early A.D. 600s to A.D. 1280, the southern piedmont was abandoned for approximately 380 years and occupied for 300 years with three periods of intensive year-round occupation totaling approximately 170 years. Key to this dry land adaptation was utilization of ephemeral streams prone to discontinuous entrenchment. During at least part of the Puebloan occupation, streams downcut and likely displayed this behavior. Discontinuous ephemeral streams have both erosional and depositional reaches that migrate through the drainage net, with different stream segments behaving differently. The cause of this periodic instability cannot be ascribed solely to drought as regional entrenchment is not always in phase (Figure 6). Regardless of the causal mechanism, these stream dynamics can limit floodwater agriculture that relies on extensive overbank inundation which is well suited for *ak chin* floodwater farming. During episodes of discontinuous entrenchment, field areas could be shifted to segments of diverging flow either on the main trunk stream or smaller tributaries with minimal labor expended in water control. *Ak chin* agriculture can serve as a key strategy for long-term food production in dry lands (e.g., Fish et al. 1992) or as an alternative or supplement to overbank floodwater farming during periods of arroyo activity. Hence, discontinuously entrenched flood plains still can be utilized for food production provided floodwater irrigation strategies are flexible.

We believe that stream entrenchment is an unlikely culprit for Puebloan abandonment of the southern piedmont during the 325-year period A.D. 725–1050, the 50-year period A.D. 1175–1225, or the ultimate depopulation at A.D. 1280. Pueblo II and Pueblo III settlements occurred along Cowboy Wash at least partly during arroyo activity. This does not deny possible deleterious effects of stream entrenchment, even if discontinuous, to floodwater agriculture in a previously non-entrenched system. Any type of shift from stable to unstable fluvial conditions reduces predictability in a resource and has to be viewed as disruptive to irrigation systems to some degree (e.g., Huckleberry 1995; Nials et al. 1989; Waters 1988), and in cases where population levels approach carrying capacity limits, stream channel dynamics can result in substantial settlement shifts (Dean et al. 1994). However, on the southern piedmont of Sleeping Ute Mountain, population density was not high, and the Puebloan groups probably adapted to episodes of entrenchment by adjusting floodwater irrigation methods and locally shifting field areas to aggrading reaches. Such a flexible irrigation strategy was probably common to alluvial valleys in the Southwest, particularly those with small to intermediate catchment areas, and perhaps in other dry land valleys of the world prone to stream entrenchment. Rather than using drought-induced arroyos as an environmental mechanism for abandonment on the piedmont, drought and consequent reduced runoff are more likely variables, as are other social mechanisms, including warfare. Unfortunately, unlike upland areas where dry farming is the main mode of food production and a minimum annual precipitation for successful crop can be defined, a threshold for drought whereby floodwater farming is no longer viable on the piedmont cannot be defined in the absence of gauged streamflow records. Whether or not drought alone is adequate for regional depopulation is less certain (Van West 1994).

Climate change in association with sociocultural processes played important roles in the prehistoric demography of the American Southwest. Understanding relationships between climate, hydrology, and human adaptation in dry land environments is worthwhile not only for the study of prehistory but also for addressing modern global change. Much is known about prehistoric climate change in the Southwest, but there still is debate as to how it affects the landscape, and particularly how it affects stream behavior and the irrigation agriculturalists that rely on stream predictability. Local alluvial chronologies from several different areas of the Colorado Plateau demonstrate that drought does not necessarily equate with arroyos and uniform erosion. Consequently, caution should be used in long-distance correlation of well-defined climatic-hydrologic models (e.g., Black Mesa) to areas that differ geohydrologically and lack historical or process-based physical evidence for stream behavior. Drought need not be the mechanism for arroyos, and arroyos need not be catastrophic to indigenous agriculturalists. Floodwater farming strategies can be flexible and adaptable to hydrological and geomorphic change.

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## Note

1. For insightful historical views of this debate, see Cooke and Reeves (1976), Graf (1983), Karlstrom and Karlstrom (1987), Knox (1983), and Webb (1985).

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