THE USE OF CHECK DAMS FOR PROTECTING DOWNSTREAM AGRICULTURAL LANDS IN THE PREHISTORIC SOUTHWEST: A CONTEXTUAL ANALYSIS

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Check dams are common archaeological features found in ephemeral drainages throughout the American Southwest. Because of the region's environmental diversity, investigators have envisioned check dams as having served a number of functions. Interpretations of function have long been normative, based largely on ethnographic parallels that have recently been the subject of criticism. A contextual analysis involving evaluation of agricultural features in relation to the local environment and human-ecological conditions appears to be a more appropriate method of examining such features. Such an assessment of one recently discovered site in western New Mexico resulted in an interpretation of check dam function that previously had not been recognized in the Southwest. Analysis of runoff and sedimentation characteristics indicates that check dams in at least one locale served to protect large fertile tracts of downstream land from periodic inundation and influxes of poor-quality sediment. The implications of these findings are discussed in regard to other check dam sites in the region.

SOUTHWESTERN ARCHAEOLOGISTS have long been interested in ancient "agricultural landforms," modifications of surface relief related to cultivation (Golomb and Eder 1964). Among such landforms, check dams—groups or series of low alignments of unshaped rocks constructed across the bottoms of ephemeral stream channels—have been of special interest, principally because they are both numerous and widespread. Check dams have been found in a variety of environmental settings throughout most of the Southwest. They have, for example, been reported from the lower Sonoran Desert (Masse 1979), where rainfall is sparse and erratic; from the Colorado Plateau (Vivian 1974), where the growing season is extremely short; and from the Mogollon region (Woodbury 1961), where neither precipitation nor temperature normally inhibit agricultural activities.

The diversity of environments in which they are found suggests that check dams served a variety of purposes (Plog and Garrett 1972). Many researchers assume that check dams were built as agricultural terraces, albeit for a variety of reasons (e.g., soil moisture retention, frost protection). The notion that crops were planted behind and upstream of such features originated with ethnographic studies of Hopi farmers conducted by Forde (1931) and Hack (1942). A few investigators (e.g., Hayes 1964) envision check dams as erosion control devices intended to keep cultivated slopes from losing soil. This interpretation is based principally on observations of Puebloan practices by Stewart and Donnelly (1943). DiPeso (1974:236-43, 1984) argues that *trincheras,* a form of check dam found in higher elevations of the Sierra Madre of western Chihuahua, Mexico, worked, in conjunction with linear borders and other features, to irrigate the flood plain of the Rio Casas Grandes by altering the hydrology and thereby increasing runoff. Based on data collected by Herold (1965), this interpretation is not widely accepted, probably because the scale of the system is too large to seem plausible and because such a check dam function has no support in the ethnographic literature.

In spite of the large number of check dam studies and the possible diversity of check dam functions, research has largely relied on normative interpretations, particularly ethnographic analogies. The appropriateness of such explanations has been criticized because they frequently involve red herrings (Cordell and Plog 1979:406, 407). Accordingly, Woosley (1980) has recently argued that, given the variety of environments found in the Southwest, prehistoric agriculture can best be understood by investigating specific, localized adaptive responses. She is correct. Agriculture is, axiomatically, the human manipulation of plants, soils, and landforms. Assessment of its related features, such as check dams, should, therefore, involve in-depth, systematic analysis of both the biophysical environment in which they are found and the habitation sites in their immediate vicinity (Butzer 1980:419). Explanations of function should be sought from the data, not inferred through the use of long-accepted, but possibly erroneous, a priori notions.

The purpose of this paper is to use such an approach to analyze a recently discovered, prehistoric check dam site in the higher elevations of the San Francisco Valley, far western New Mexico. This study involves detailed appraisals of both ancient agricultural landforms and the physical environment, combined with an evaluation of the human-ecological conditions of the site. First, the habitational area of the site and the check dams are described. Next, the agricultural environs and major agro-ecological problems are elucidated. Finally, an interpretation of the check dams' function—one that previously has not been recognized in the Southwest—is proffered, with a closing discussion of its implications for other check dam sites in the region.

CHECK DAM SITE

Site USFS 06-04-109 is situated in the Gila National Forest, Grant County, New Mexico. It is located approximately 14 km south of the present-day village of Mule Creek near the divide between the drainages of the San Francisco and Gila rivers (Figure 1). The site is relatively isolated. Although others do exist in the general area, the nearest site is almost 2 km away. At an elevation of 1925 m, rainfall and temperature are today suitable for dry farming, that is, agriculture dependent solely on the water available from rainfall without any use of runoff (Lawton and Wilke 1979:3-4). Indeed, such high elevations might be better suited for agriculture than lower ones during times of drought because they receive more-dependable, orographic summer rainfall (see, e.g., Schoenwetter and Dittert 1968:50, 52). Precipitation averages between 400 and 500

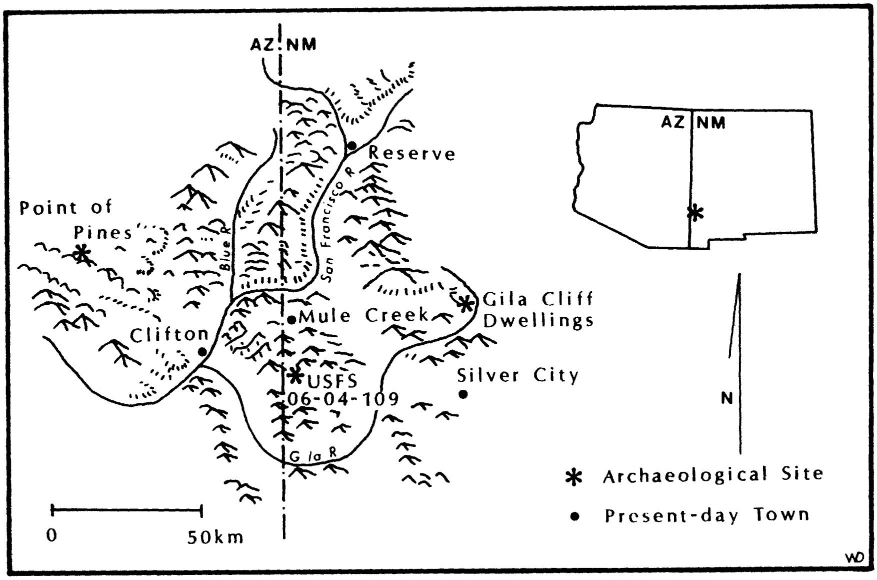

Figure 1. The San Francisco and Neighboring Valleys

mm annually (Houghton 1983). The growing season is greater than 150 days, and occasional midsummer freezes, that can make agriculture precarious (Martin et al. 1956:192-97), occur only above 1980 m. Pines (*Pinus ponderosa* and *P. edulis*) characterize the highland slopes (Pase and Brown 1982). In some places, however, slopes are minimal, and woodlands give way to patches of open grassland (Figure 2), where grama grasses (*Bouteloua* sp.) dominate (Alexander et al. 1984:15). Although they have characteristics of alpine meadows, these grassy areas are both referred to locally and known technically as *cienegas* (Hendrickson and Minckley 1984).

The site itself lies at the interface of gently rolling woodlands and a cienega (Figure 3). It is a Mogollon settlement of moderate size. The area that contains both ceramic and lithic artifacts and/or remnants of permanent habitation structures is approximately 10,000 m^2. Ceramics found on the site are of limited variety. Plain brown wares and corrugated wares are abundant. Painted wares include mostly Mimbres Classic Black-on-White and a lesser amount of Mimbres Boldface Black-on-White. Architecture, as evidenced solely by surface remains (Inset, Figure 3), includes four pueblo room blocks, containing approximately 8, 10, 16, and 24 rooms, and one great kiva. Also, one surface depression may well be the remains of a pithouse. The ceramic evidence, in conjunction with the architectural remains, suggests that the site has at least two components. The possible pithouse and the limited amount of Mimbres Boldface Black-on-White ceramics indicate a small component dating between A.D. 750 and 1000 (Anyon and LeBlanc 1980). The pueblo room blocks and the abundant

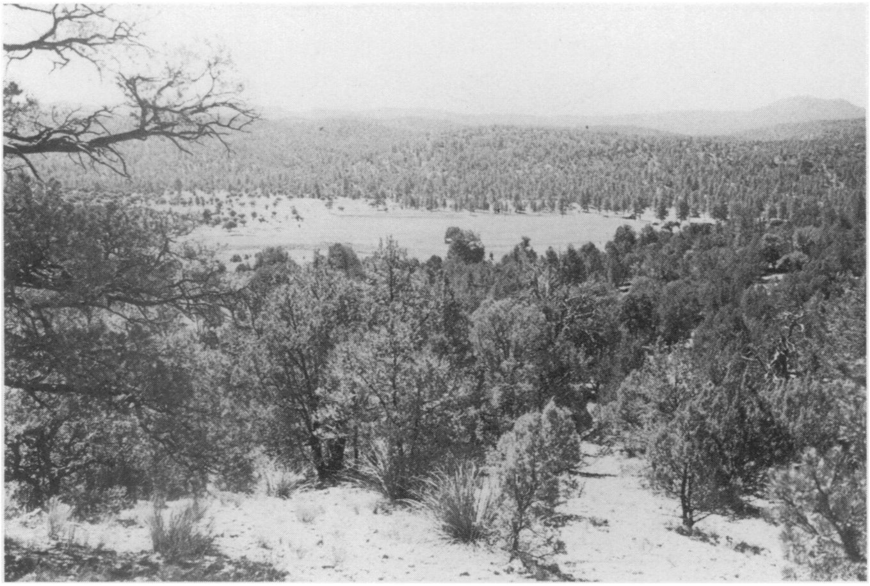

Figure 2. View of an Upland Cienega in the San Francisco Valley

Mimbres Classic Black-on-White ceramics are evidence of a larger component that dates between A.D. 1000 and 1150 (Anyon and LeBlanc 1980).

Estimating the maximum number of persons that inhabited a prehistoric site at any one time is essential for contextual analysis. It is also difficult and calls for a great deal of caution. Difficulties with the contemporaneity of structures (Patterson 1963; Schacht 1984), the extent to which each structure was inhabited (Plog 1975), and the appropriateness of ethnographic analogies (LeBlanc 1971) are commonly encountered in archaeological investigations. If it can be assumed that all structures were occupied contemporaneously and that every room was used, the most difficult problem is to ascertain the number of people represented by either the total floor area or each room. In one study, Casselberry (1974) found that the population of multiple family dwellings was approximately one-sixth of the total floor area measured in square meters. Applying Casselberry's figure to the approximately 800 m^2 of pueblo floor space, we can project that as many as 135 people inhabited the check dam site. In separate studies, Hill (1970) and Longacre (1976) accepted each room as representing 2.8 persons. Using this figure, we can estimate a maximum population of 165 for the site. Probably no more than this number of people inhabited the site at any moment in time.

The most important characteristic of the site is neither its age nor its size, but rather the check dams found in association with it (Figure 3). Twenty-five of these are located in a small tributary that drains the wooded, moderately sloping lands north of the site proper, and another fourteen are located in a

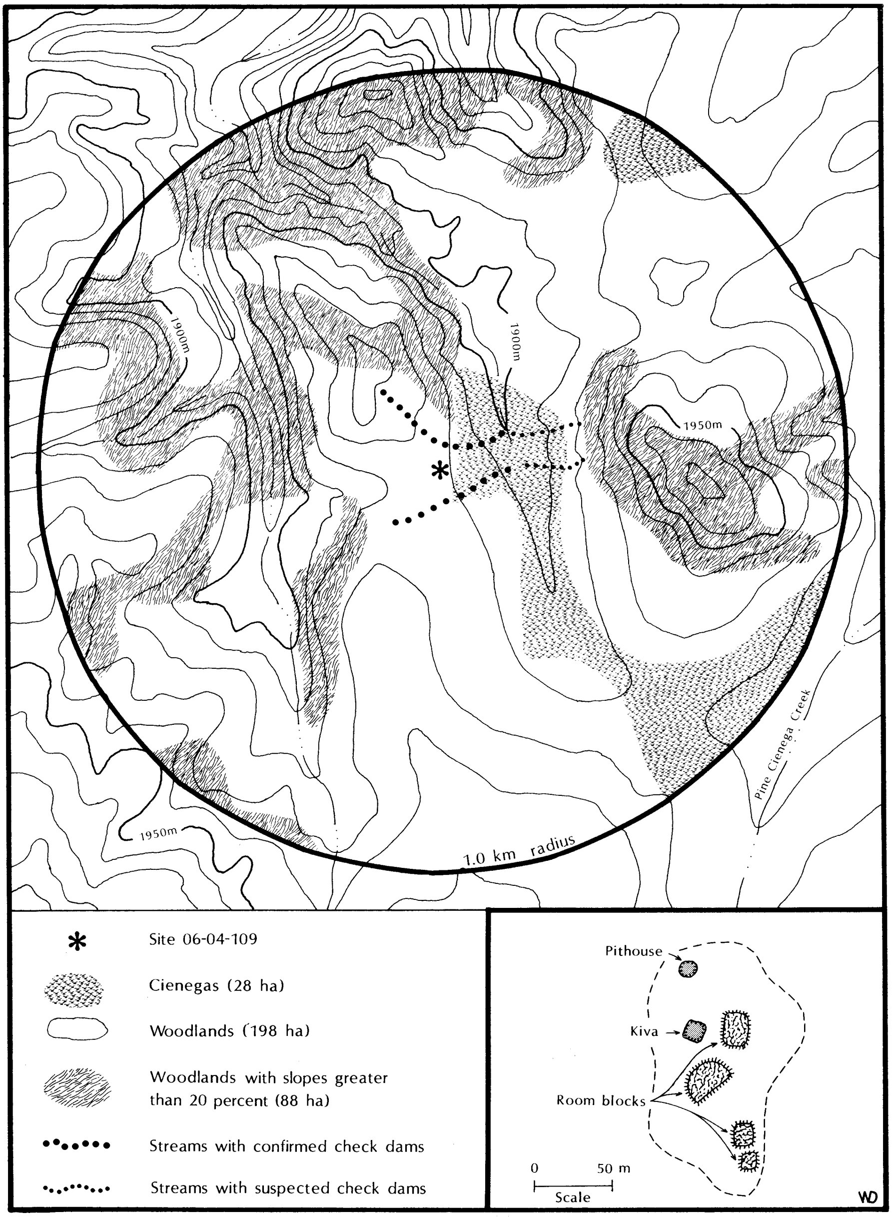

Figure 3. Environs within a 1 km Radius of Site USFS 06-04-109

similar stream bed south of the habitation structures. A few fragments of check dams were also found in two tributaries draining the uplands east of the cienega. There are no other prehistoric agricultural features in the vicinity. Many of the check dams are nearly intact (Figure 4), but only fragments of others have survived into modern times (Figure 5). On the whole, the series of check dams in the northern stream channel is more complete than those in the southern channel (Figure 6) or opposite the cienega. Individual check dams in the northern channel are highly fragmented however, in part, perhaps, because of the comparatively steep gradient that has resulted in incision. In the southern channel, check dams are intact and easily identifiable only in the far upstream portion. A few fragments found further downstream indicate that the check dam series once probably involved most of the stream course. Vehicular traffic associated with ranching and most recently with pot hunting appears to be responsible for the destruction of check dams and, indeed, of much of the physical environment in this section of the drainage. Unfortunately, the extent of check dams in streams across the cienega and, hence, their importance and cause of deterioration cannot be determined at this time. It can only be surmised from their locational characteristics that they functioned in a manner similar to those in the streams draining the uplands surrounding the habitation site.

The lengths of the check dams and the distances between them vary considerably. The longest dam measured approximately 15 m, the shortest only 3 m. In one case, two check dams were only 3 m apart, while the distance between two others in the same stream bed measured 33 m. A direct association in which intervening spaces are short on steep slopes and long on flatter

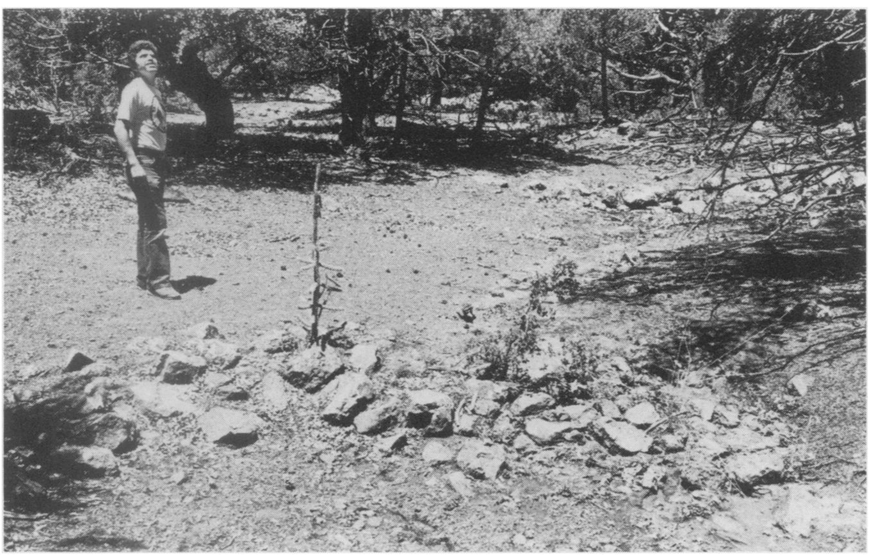

Figure 4. An Upstream View of a Series of Nearly Intact Check Dams in the Upstream Portion of the Channel along the Southern Edge of Site USFS 06-04-109

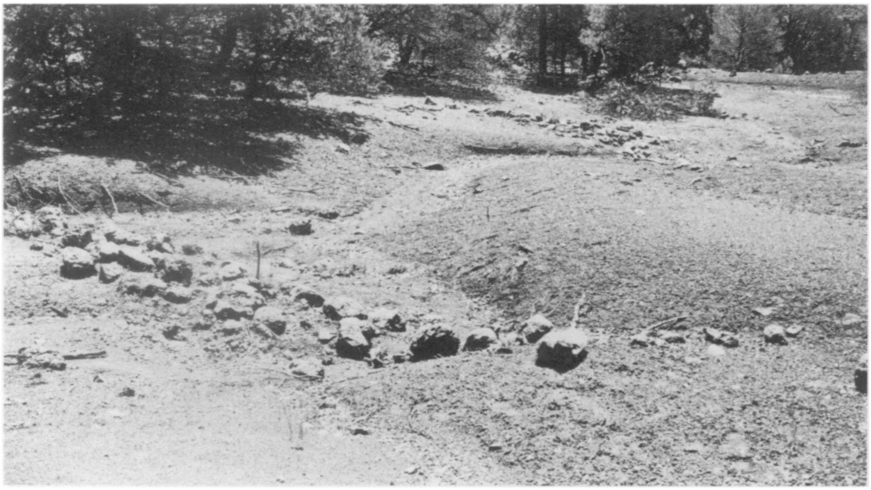

Figure 5. A Downstream View of a Series of Check Dams Breached by Erosion in the Channel along the Northern Side of Site USFS 06-04-109

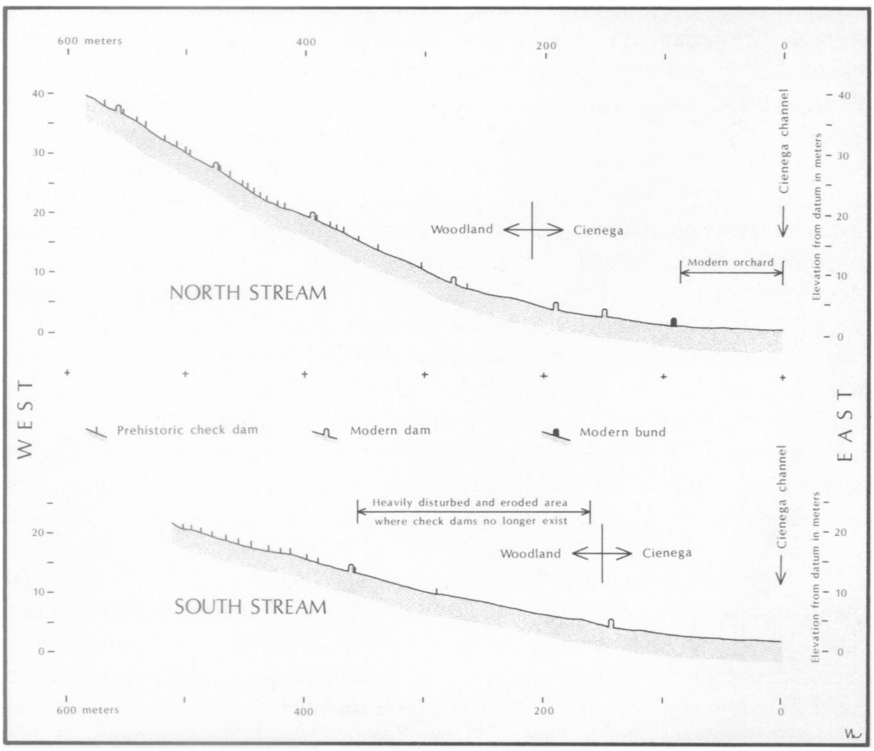

Figure 6. Profiles of Cienega Tributaries Containing Check Dams Illustrated in Figures 4 and 5

slopes (see, e.g., Leopold and Bull 1979) was not found. Although the greatest distance between check dams is found at the downstream end of the northern series, where the stream gradient is only 8 percent, at least one intervening distance as small as 5 m is found along this stretch. Toward the upstream end of the series, where the slope is 15 percent, the distances between check dams might be expected to be short and indeed are as little as 3 m. However, some check dams there are separated by as much as 15 m.

Given the lack of any clear-cut relationship between slope and intervening distance, the height of the check dams might be expected to vary in compensation (see, e.g., Schwab et al. 1981). For example, where both the slope and the distance between features are great, check dams might be expected to be higher than in places where the slope is low and the intervening distance short. Such is not the case here. Although erosion has damaged several check dams, all appear to have been approximately 0.3 to 0.5 m high at the deepest point of the stream channel (Figure 7). The check dams are not as well constructed and as uniform in appearance as those at some other sites in the Southwest (e.g., Rohn 1963:Fig.2). Furthermore, they did not make maximum use of the available channel.

Sediment has accumulated behind each check dam. It does not, however, extend all the way to the next feature upstream in those cases where spacing is great. The sediment trapped behind the check dams tend to be dark, coarse, and of slightly acid to neutral reaction (Table 1). The color is largely a function of organic matter. It has been at least 800 years since the sediment was deposited. Over this period, much organic matter, largely in the form of decomposed pine litter (needles and cones), has accumulated. The coarse texture is a function of both high stream velocity and depositional processes in the upstream reaches of drainages (Wertz 1966). It is also common behind both modern (Glassow 1980:51) and prehistoric (Sandor 1983:73) check dams in other parts of the Southwest. Fertility is low because of the nature of both the organic matter and the texture of the sediment. Pine litter is acidic, thus contributing to the moderately low reaction. The pH level is also determined in part by the sparsity of clay materials that hold available base nutrients, a condition which reduces the cation exchange capacity (Brady 1974:32-38, 99-106). Sandor (1983:254-57) argues that the low fertility of sediment trapped behind check dams is the result of nutrients being depleted by cropping. It is more likely, at least in this case, that the small clay fraction is the principal factor.

On the basis of their length, height, spacing, total areal extent, locational characteristics, and sediment, it is apparent that these check dams were not constructed to create planting surfaces (terraces), as the most popular normative interpretation would hold. The total cultivable area resulting from their construction is very small: less than 0.4 ha is involved in the two northern and southern series of check dams. These "plots" also had relatively low soil fertility.

If the prehistoric farmers had expended the energy to construct check dams to create terraces, it seems highly unlikely that they would have waited several years for sediment of poor quality to accumulate. It is more likely that they would have hauled in sediment, an activity that is labor intensive (Ashbee and Cornwall 1961; Erasmus 1965), but which has been documented elsewhere in the region (see, e.g., Donkin 1979:50, 102) and could have been carried out relatively quickly. At an average depth of approximately 0.25 m, the 0.4 ha of sediment behind check dams has a total volume of only 1,000 m^3. Studies conducted under the auspices of the United Nations (1961:18) revealed that

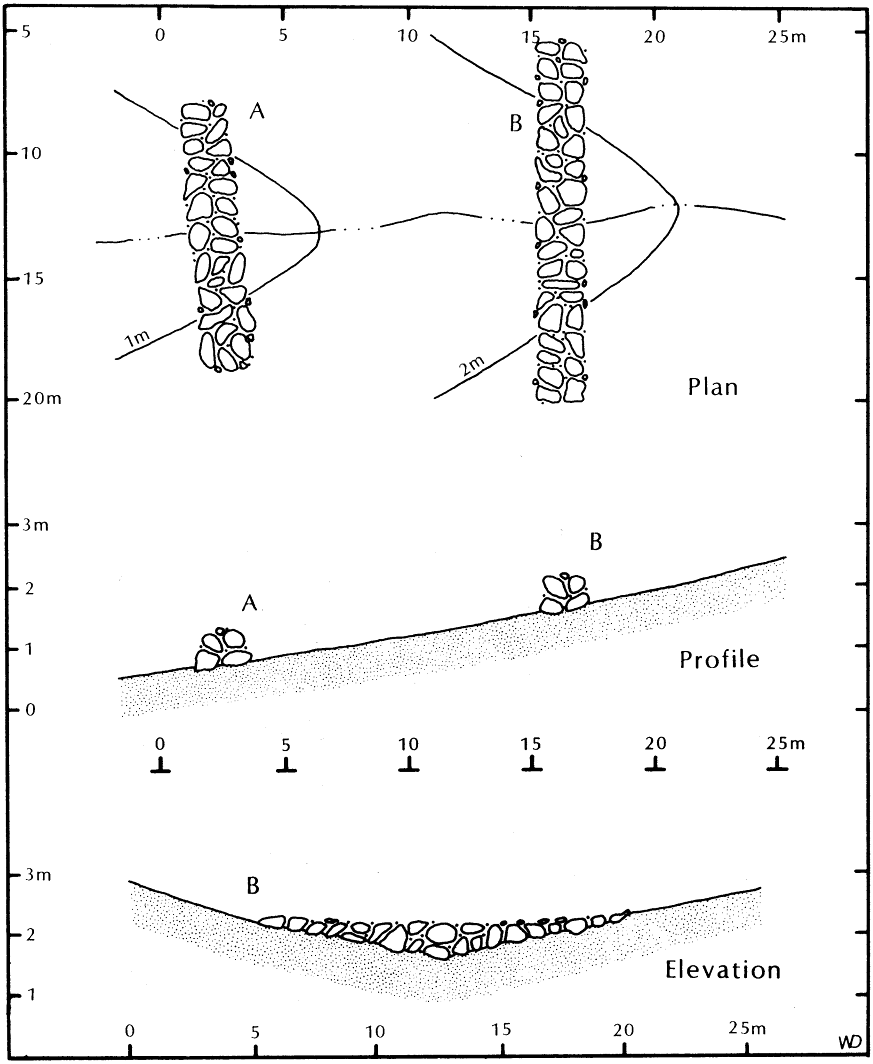

Figure 7. Schematic of Check Dams as They Were Probably Constructed

TABLE 1
Sediments Trapped Behind Four Intact Check Dams*

Sample (0–10 cm)	% Sand	% Silt	% Clay	Texture	Moist Color	Reaction (pH)
Check dam 7	86	8	6	loamy sand	7.5YR 3/2 dark brown	6.5 slightly acid
Check dam 8	74	18	8	sandy loam	10YR 3/2 very dark greyish brown	6.2 slightly acid
Check dam 9	74	20	6	sandy loam	10YR 3/2 very dark greyish brown	6.6 neutral
Check dam 10	72	22	6	sandy loam	7.5YR 3/2 dark brown	6.2 slightly acid

*The four check dams for which sediments were analyzed and data are presented here are in the stream along the south side of site USFS 06-04-109. These check dams were sampled because they are the best preserved in the area. Check dam number 7 is the seventh one from the top of the drainage; number 10 is the tenth (see Figure 6).

"soft" sediment can be excavated by hand and carried 0.5 km in baskets at a rate of approximately 0.5 m^3 per person/work day. At this rate, the sediment behind all the check dams at site USFS 06-04-109 could have been brought in by a labor force of 33 workers (one-fifth of the site's estimated population of 165) in only 60 days. Hand-filling would have been faster than natural sedimentation and would have resulted in a better-quality planting medium.

Furthermore, in some cases cultivation behind check dams would have been, as Woosley (1980:33) claims, "a highly capricious type of farming" because runoff in ephemeral streams is often of a sufficient velocity to have destroyed crops. The coarse texture of the sediment behind the check dams suggests that such conditions existed near site USFS 06-04-109. Given their characteristics, it is highly unlikely that the check dams were intended to create planting surfaces. Instead, they can best be explained as an effort to protect agricultural lands.

AGRICULTURAL ENVIRONS OF THE CHECK DAM SITE

The lands most probably used for farming prehistorically were the cienegas and the surrounding, moderately sloping woodlands. Within a 1 km radius of the check dam site is a total of 28 ha of cienega land (14 ha of which are adjacent to the site), 198 ha of woodland with slopes less than or equal to 20 percent, and 88 ha of land with slopes greater than 20 percent (Figure 3).

The cienegas have soils that are generally classified as fine-loamy, mixed, mesic Cumulic Haplustolls of the Manzano series of the Manzano-Ruidoso association (Parham, Paetzold, and Souders 1983:33, 80, 158). These soils are typically very dark brown (10YR 2/2), in part because they have a high organic content (2-3 percent). They are fertile, with a reaction that ranges from neutral (6.6 pH) in some locales to moderately alkaline (8.4 pH) over most of the area. Being cumulic, cienega soils tend to be deep and well drained. The effective rooting depth is often greater than 150 cm, and the texture varies according to depth from loam to clay loam. Permeability is, for the most part, moderate (1.5-5.1 cm/hr), and the available water capacity is usually very high (0.16-0.21 cm/cm). Runoff is slow, and the hazard of erosion is slight. Overall, edaphic limitations to agriculture, especially dry farming, are few. However, two related problems do exist. First, the slow rate in which water runs off the cienega can cause occasional inundation, or ponding; and rapid runoff from surrounding slopes exacerbates the ponding problem by contributing additional water. Second, the abrupt change of slope between the surrounding uplands and the cienega causes a marked decrease in stream velocity, which results in the deposition of coarse and less-fertile sediments not unlike those that have accumulated behind the check dams.

Surrounding the cienegas are moderately sloping woodlands with soils classified as clayey, montmorillonitic, mesic Lithic Argiustolls of the Luzena series (Parham et al. 1983:33, 79, 158). These soils are dark brown (7.5YR 3/2) and have an organic content of 1-2 percent. They vary greatly in reaction, being slightly acid (6.1 pH) in a few places and mildly alkaline (7.8 pH) in most. Fertility, therefore, varies spatially but for the most part is adequate for agriculture. Although shallow, these soils are well drained. At 18-50 cm, the effective rooting depth is much less than in the cienegas. The texture is coarse, ranging from gravelly loams to gravelly clays, but the clay content can be as high as 60 percent in some cases. Accordingly, permeability is moderately slow (1.5-5.1 cm/hr), the available water capacity is very low (0.10-0.14 cm/cm), runoff is medium, and the hazard of erosion is moderate. These lands are not as good as those of the cienega. However, they are still highly suitable for agriculture, especially of a burn-plot type, such as that discussed by Sullivan (1982), or of some variations of the ecologically sound *chitimene* system found today in many parts of Africa (Manshard 1974:57-59). Rockiness and the shallow depth to bedrock are the principal edaphic limitations that directly affect agriculture on the moderately sloping woodlands. The high rate of runoff and the hazard of erosion are, of course, also of some consequence.

As with the moderately sloping woodlands, the soils of the steeper slopes are classified as clayey, montmorillonitic, mesic Lithic Argiustolls. However, they are of the Luzena series of the Rock outcrop-Luzena association (Parham et al. 1983:44, 160). These brown (7.5YR 4/2) soils are lighter in color than those of the other areas, largely because they have an organic content of less than 1 percent. Soil reaction is neutral (6.6-7.3 pH). The development of these soils on steep slopes has contributed to their gravelly, clay-loam texture. The percentage of clay is most often between 35 and 60 percent. As a result, permeability is very low (1.5-5.1 cm/hr), as is the available water capacity (0.06-0.10 cm/cm). Although these soils are well drained, runoff is rapid because of the high clay content, and the hazard of erosion is high. Limitations on agriculture are both numerous and significant. Undoubtedly, the greatest and most direct problems with these soils are their shallow depths and the presence of numerous rock outcrops. It is doubtful that slopes greater than 20 percent were cultivated prehistorically.

Given the techniques known to have been employed and the types of land known to have been farmed prehistorically in the Southwest, it can be surmised that people residing at site USFS 06-04-109 probably cultivated the cienegas and the moderately sloping woodlands, which were most suitable for agriculture. Of course, there is no way of confirming such a conclusion at this time. Other than the check dams discussed above, no earthen or rock features of prehistoric age are found in either the cienegas or the surrounding woodlands. It is most likely that the ancient farmers relied on brush devices, if anything, to divert, slow, or spread runoff. Such features have been used in the Southwest (Castetter and Bell 1942:158-61), are easily constructed and replaced as long as materials are available and there is a need for their use (Doolittle 1984:128), and would not have survived long enough to appear as archaeological evidence (Sauer 1963:161; Woodbury 1961:36). It is also possible that no other water diversion or conservation devices were necessary, as rainfall in the area is today, and presumably was prehistorically, more than adequate in both amount and timing (Carter 1945:84-85; Winter 1974:134).

The cienegas and the moderately sloping woodlands both would have been good lands for practicing prehistoric dry farming. Although the cienegas have somewhat better soils than the surrounding slopes, they are limited in areal extent and suffer ponding on occasion. In addition, their fertile soils can be buried by materials eroding off the surrounding slopes. The moderately sloping woodlands cover a much greater area than the cienegas, and, although not ideal or trouble free, they were cultivable. In sum, a total of 226 ha of land was most suitable for prehistoric dry farming within a 1 km radius of the site. The question now is whether a sufficient amount of food could have been produced on these lands to feed the 165 people who probably inhabited the site. The answer is clearly yes.

Maize (*Zea Mays*) and beans (*Phaseolus* sp.) were the principal crops consumed prehistorically in the Southwest. These cultigens have similar caloric values per kilogram, approximately 3,600 cal/kg for maize and 3,400 cal/kg for beans (Leung 1961). On the average, each person requires approximately 2,400 cal/day, or 876,000 cal/yr (Kirschmann 1975:233-34). If we use the caloric value for beans, because it is the most conservative, the caloric requirements of one person can be satisfied by 258 kg of maize, beans, or some combination of the two each year. In a recent study, Hastorf (1980:100) ascertained that as much as 850 kg/ha could have been produced prehistorically by dry farming without fallowing in the neighboring Mimbres Valley. This estimate, she found, had to be reduced by 40 percent because other studies (Staten, Burnham, and Carter 1939) of productivity demonstrated that individual fields in the Southwest were either fallow or unproductive for an average of two out of every five years.

On the basis of these findings, it can safely be assumed that ancient dry farming produced, on the average, 510 kg/ha. If we further allow for 15 percent of the crop being lost in storage (National Academy of Sciences 1978:76), only 0.6 ha of the lands surrounding site USFS 06-04-109 would have been needed to support one person each year without any reliance on hunting or gathering wild foods. In other words, the 226 ha available within a 1.0 km radius of the site could have fed 375 people. The estimated maximum population of 165 could have been fed from only 100 ha, or 45 percent of the land available near the site, especially if certain problems were overcome. Adequate land would have been available even if conditions were not as favorable for agriculture as they are today.

AGRO-ENVIRONMENTAL PROBLEMS

Two types of cultivable land exist at the site, each with unique problems that require attention: ponding and sedimentation on the cienegas and erosion on the woodland slopes. Because it is surrounded by higher elevations on three sides and tall trees on four, the cienega adjacent to the site almost has the appearance of being the center of a shallow, interior drainage system (Figure 8). One intermittent stream does drain the cienega. It has, however, an average gradient of only a little more than 1 percent, with some places being virtually

Figure 8. View of Cienega Adjacent to Site USFS 06-04-109. (This view is looking due east from the site. The dark soil, sparse grass, and young junipers characterize the center of the cienega where ponding was a problem. Drainage is to the left. The stock tank on the right also appears in Figure 6 as the modern feature furthest downstream in the south stream.)

flat, and one 5 m stretch even having a slight uphill grade. The longitudinal profile of the stream is discontinuous (Schumm and Hadley 1957), with repeated floor steps resulting principally from the inflow of tributary streams (Henderson 1966:394-98). This condition is most clearly visible in the 200 m section of the stream course closest to site USFS 06-04-109 (Figure 9). Here, the two streams with confirmed check dams draining the uplands surrounding the site and the two streams with fragments of a few check dams draining the uplands opposite the site, east of the cienega, converge with the main cienega channel (Figure 3). Throughout its length, the main cienega channel has a natural cross section that is almost imperceptible. It is broad and very shallow with a flattened U shape (Figure 10). Slight stream braiding is also evident, and numerous depressions are found in those places where the tributaries converge with the principal cienega channel. Overall, such characteristics are indicative of a low discharge and a very slow velocity (Wilcock 1971), combined with sheetwash on the surrounding slopes and gullying in the upstream reaches of the tributaries (Butzer 1982:134-35).

For the most part, the tributaries as they cross the cienega have profiles (Figure 6) and cross sections that are similar to those of the principal stream. Ponding has occurred where the tributaries converge with the main channel (Figure 11). Here, the tributary and main channel gradients are flat, or nearly

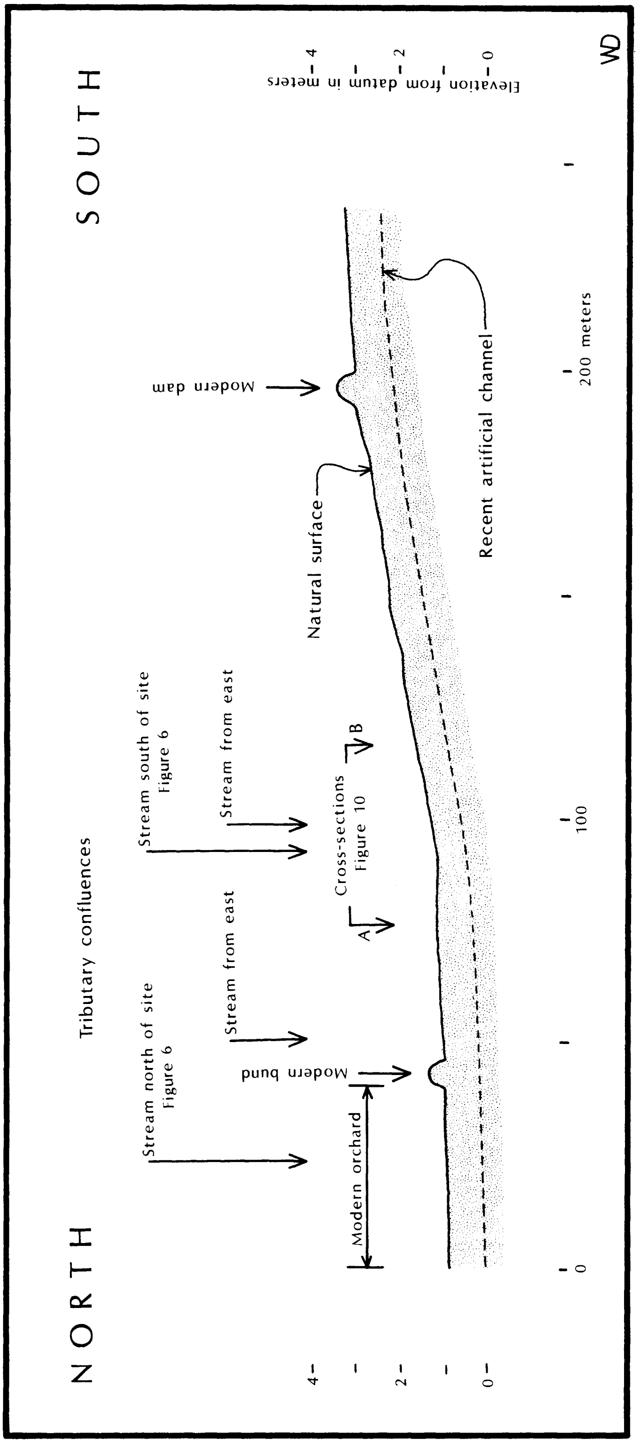

Figure 9. Longitudinal Profile of the Stream Draining the Cienega

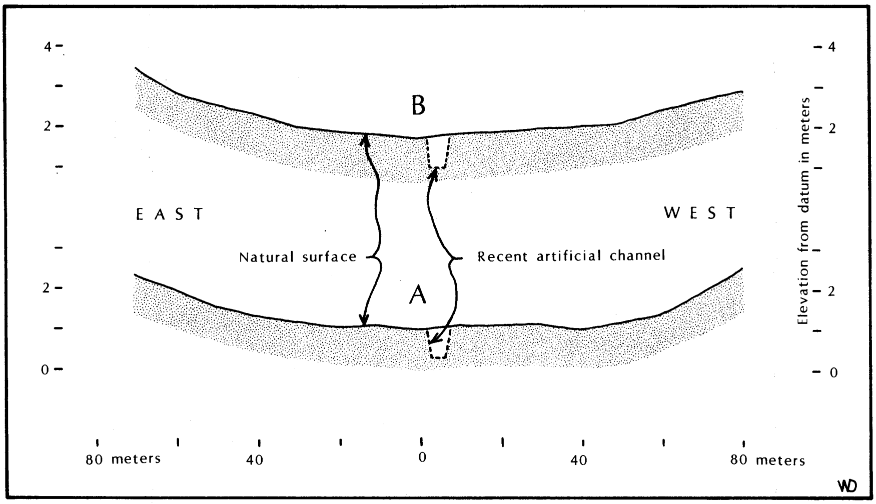

Figure 10. Cross Sections of the Cienega

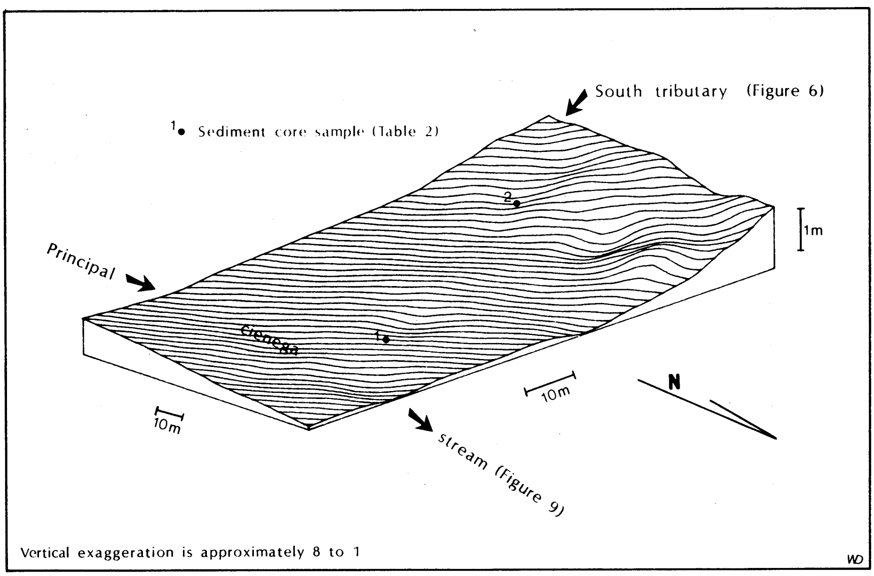

Figure 11. Computer Map Showing the Topography of the Cienega Where Ponding and Sedimentation Were Problems. (Here the tributary streams with check dams south of the site [Figures 4 and 6] converge with the principal cienega channel [Figure 9]. This area is between the cross sections illustrated in Figure 10.)

so, and abundant grasses help to further reduce the velocity of runoff. Summertime thunderstorms in the Southwest frequently produce great amounts of rain in very brief periods (Turnage and Mallery 1941:16-17), even during prolonged droughts (Schoenwetter and Dittert 1968:50). During and immediately after such storms, runoff can pool up on the cienega. It is because of this ponding that the Spanish word cienega, meaning swamp, marsh, or wet meadow, is applied to this area and others like it in the region (Hendrickson and Minckley 1984).

Collection and analysis of detailed hydrologic data from the small drainages with check dams near site USFS 06-04-109 were not possible because both ancient and recent activities have altered the natural surface characteristics (Figure 6). However, little doubt exists that the problem of ponding on the cienega was as much a function of the rapid runoff from the surrounding slopes as it was of the poor drainage of the cienega itself. The ephemeral streams that drain the upland areas and empty into the principal stream of the cienega adjacent to the site each have a very small watershed (less than 3 ha). Drainages as small as these can be effective producers of runoff (Mueller 1972). Relatively speaking, they are more efficient runoff producers than larger drainages (Tadmore, Shanan, and Evenari 1960). For example, in one study, Shanan (1974) found that runoff can begin on small catchments after as little as 2.5 mm of rain, while larger watersheds required at least 7.0 mm of rain. Although these figures were determined empirically for another area, the principles from which they were derived (Morris and Wiggert 1972:376-86) are theoretically applicable to other places, including locales in the San Francisco Valley. There are at least five reasons why little water infiltrates during overland flow and, hence, why these small drainages effectively generate runoff. The streams have relatively steep gradients (see, e.g., Wheeler 1979); it takes only a short time for runoff to reach peak flow (see, e.g., Horton 1945); a substantial part of the surface area is characterized by impermeable rock outcrops (see, e.g., Betson 1964); the soils have a high clay content (see, e.g., Sandor 1983:56); and they are thin and easily eroded (see, e.g., Kirkby and Chorley 1967).

Rapid runoff from the upland slopes has resulted in the erosion of sediments, the coarser ones of which have been deposited on the cienega (see, e.g., Butzer 1982:134). Under typical conditions, the Manzano series soils that characterize cienegas have a very thin, fertile A horizon, with a loam texture, and very thick clay loam B and C horizons. Those of the periodically inundated areas, however, are characterized by deep, sandy, and relatively infertile alluvium that has resulted from anthropogenic erosion (Table 2). The thickness of this coarse alluvium decreases and the degree to which it has been reworked increases with the distance from the point where the slope changes abruptly, near the edge of the cienega, to the center of the cienega where the slope is nearly flat (Figure 11 and Table 2). The difference in the thickness of these sediments and the degree of reworking are the result of differential stream velocities. At the edge of the cienega, deposition is greater and the coarse alluvium is thicker and more uniform than at the center, because of the de-

TABLE 2
Cienega Sediments Compared to Typical Manzano Series Pedon

Alluvium/Horizon	Depth (cm)	% Sand	% Silt	% Clay	Texture	Moist Color	Reaction (pH)
Core sample 1*							
Deposition resulting from	0-15	45	47	8	loam	7.5YR 3/3 dark brown	7.0 neutral
anthropogenic erosion	15-30	60	30	10	sandy loam	7.5YR 3/2 dark brown	6.4 slightly acid
	30-45	48	40	12	loam	7.5YR 3/2 dark brown	6.9 neutral
Buried soil	45-60	14	50	36	silty clay loam	10YR 3/2 very dark greyish brown	6.4 slightly acid
	60-75	27	59	14	silt loam	10YR 3/3 dark brown	7.7 mildly alkaline
Core sample 2**				8			
Deposition resulting from	0-15	67	25	6	sandy loam	7.5YR 3/2 dark brown	6.4 slightly acid
anthropogenic erosion	15-30	66	28		sandy loam	7.5YR 3/4 dark brown	6.5 slightly acid
	30-45	64	28		sandy loam	5YR 3/2 dark reddish brown	6.5 slightly acid
	45-60	50	32	8	loam	7.5YR 3/2 dark brown	6.7 neutral
Buried soil	60-75	17	57	18	silt loam	10YR 3/3 dark brown	6.5 slightly acid
				26			
Typical Manzano Pedon (Parham et al. 1983:80)							
A1***	0-8	—	—		loam	10YR 2/2 very dark brown	8.0 moderately alkaline
B2	8-65	—	—	10-25	clay loam	10YR 2/2 very dark brown	8.0 moderately alkaline
C1ca	65-90	—	—	18-34	clay loam	7.5 YR 3/2 dark brown	8.4 moderately alkaline
C2	90-150	—	—	18-34	clay loam	7.5YR 3/2 dark brown	8.4 moderately alkaline
				18-34			

*From center of cienega near the principal stream (see Figure 11)
**From edge of cienega where the tributary stream gradient flattens markedly (see Figure 11)
***Possibly alluvium resulting from anthropogenic erosion, and not an A horizon

creased velocity resulting from the marked flattening of the stream gradients. The coarse texture of these sediments is further testament to the high velocity of the streams draining the uplands (Butzer 1982:130). Silt and especially the fertile clay fraction are typically carried by streams, even at very slow velocities. Sand, however, requires much more energy to be eroded. That it has accumulated, both on the cienega (Table 2) and behind check dams further upstream (Table 1), is indicative of high stream energy that has contributed to ponding and sedimentation on the cienega.

The dark color of the alluvium is principally a function of the organic matter that has accumulated over the past several centuries. Illuviation of this organic matter, resulting in large part from ponding, is partially responsible for the dark color of the lower strata. This organic material is comprised of grasses, particularly *Bouteloua* sp., and coniferous litter that has washed down from the wooded slopes (see, e.g., Nabhan 1984). The abundance of such litter along with the paucity of clay has resulted in the mildly acidic reaction of the alluvium.

Both periodic ponding and increased sedimentation would have been problems for ancient cultivators. Ponding could, at least on occasion, have reduced or completely stopped the free entry of oxygen into the soil (Briggs 1977:89-90), fostered root diseases that cut the supply of plant nutrients (Poehlman 1979:311), and caused lodging (Poehlman 1979:159-69, 307). All of these conditions could severely damage or totally destroy a crop. Influxes of coarse sediments of low fertility would have been a twofold problem. First, sedimentation could bury a young crop; and second, the deposition of coarse sediments as deep as those found near site USFS 06-04-109 would have modified growing conditions for the worse. Specifically, the optimal soils for maize cultivation are silt loams and clays greater than 50 cm deep (Thorne 1979:120). Such conditions are typical of Manzano series soils (National Cooperative Soil Survey 1976). They do not, however, exist in those places where the cienega has been subjected to inundation and the deposition of coarse sediments.

The rapid runoff has also contributed to the erosion of the surrounding woodland slopes. Evidence of erosion is clear and widespread. Rills are common over most of the slopes, and gullying is apparent, especially in the tributaries that contain check dams and empty onto the cienega. Indeed, gullies have breached many of the check dams (Figure 5). A few check dams were constructed in small gullies that breached other dams. The presence of such additional and remedial or corrective features indicates that attempts were made to arrest accelerated erosion after the original check dams were built. Although the extent, impact, and timing of erosion cannot be determined at this time, it is clear that it existed in the eleventh century A.D., when agriculture was a widespread practice in the region and the check dams were built. It is unlikely, however, that the check dams associated with site USFS 06-04-109 were built principally to control erosion on the upland slopes surrounding the cienega. Other features such as "linear borders" (Woodbury 1961:12-13)—rock alignments similar to check dams but located on adjacent hillsides probably to impede sheet and rill erosion—are not evident on the slopes near the site. If erosion was a major problem on these uplands prehistorically, such features undoubtedly would have been constructed. Furthermore, if the check dams had been intended to preserve soil on these uplands, they would have conserved only 0.4 ha, the total area they encompass. The check dams appear to have been constructed in order to protect agricultural lands, but not those of the upland slopes.

CHECK DAM FUNCTION

For agriculture, the cienegas are the best lands in the vicinity. They have soils that are fertile, deep, rock-free, and of appropriate texture. They are also the only lands on which agriculture has been practiced in recent times. Periodic ponding and influxes of coarse sediments are the only factors of consequence that can keep agriculture from being successful on the cienega lands. There are, however, a number of ways these problems can be solved.

Perhaps the simplest way is to construct series of check dams in the channels of the ephemeral tributaries that drain the upland slopes (Turner and Doolittle 1978:300). Recent field studies indicate that 1.65 m of low rock alignment can be built per person hour (Fish and Fish 1984:156). At this rate, the confirmed check dams near site USFS 06-04-109 could have been built in a total of 236 person hours. Assuming conservatively that only one-fifth of all the check dams constructed contemporaneously in prehistoric times have survived to the present and that the average work day was six hours long (Barlett 1980:152), we can calculate that the estimated labor force of thirty-three persons from the site could have built the entire check dam complex surrounding the cienega in only six days. Certainly this is not a great labor expenditure, especially in comparison to the benefits received. Maintenance also would not have involved much work, in part because it would have been carried out periodically (Doolittle 1984).

The importance of the check dams, however, does not necessarily lie in how easy they are to build and maintain, but rather in how effectively they alleviate the perceived problems. Series of check dams do in fact constitute a most effective means of controlling both ponding and alluviation on lands downstream. As impediments to natural channel flow, check dams dissipate energy, thereby increasing the time it takes water to run off (Henderson 1966:174-80). Such decreases in stream velocity would give the cienega more time to drain, thus alleviating, in part or in full, the problem of ponding. Reducing the stream velocity would also have decreased the rate of erosion on the slopes and of gullying in the tributary channels. Furthermore, it would have greatly lessened the problem of sedimentation on the cienega.

The effectiveness of the check dam complex was unquestionably greatest immediately after construction. It is highly probable, however, that the dams also functioned quite effectively after sediment had accumulated behind each feature. Hays and Palmer (1937) found, for example, that the runoff rate in a watershed containing check dams with sediment accumulations was approximately one-half that measured in a similar and adjacent drainage without such features. Two factors are responsible for this reduction in velocity. First, the transformation of a smooth slope into a stair-stepped to "terraced" slope increases both the distance runoff must travel and the time it takes runoff to reach peak flow. Second, the collection of sediment behind the check dams decreases the slope angle or effective stream gradient. The sediment trapped behind the check dams can, of course, also alter the runoff characteristics. If the sediment in a drainage with check dams is no different from that in a similar drainage without check dams, the total discharge in each drainage will be identical, even though the runoff rates will be different. If, however, the sediment associated with the check dams is more permeable than that in channels without such features, some water will be absorbed, and both the runoff rate and the total discharge will be lower in the former drainage than in the latter (Brady 1974:238). Such is the case with the check dams at site USFS 06-04-109. Here, sediment trapped behind the check dams is coarser (Table 1) than that of the surrounding slopes and the drainage as a whole. In effect, the accumulated sediment helps to decrease the total discharge and, hence, the stream velocity. The accretion of coarse sediment, both behind and upstream of the check dams and on the cienega downstream, is, by itself, evidence of the very type of fluvial process that the check dams were designed to impede.

Further evidence that the check dams were intended to control runoff and thereby remedy both ponding and sedimentation exists in the form of similar, modern water-control devices near the site. Indeed, both problems were more significant in times past than they are today. Recent ponding has been alleviated by a number of means. Earthen dams constructed in the cienega (Figures 6 and 8) to create stock tanks have concentrated water in a few selected natural locales, rather than in several scattered ones. In one place, an earthen bund has been constructed to divert runoff around an orchard planted on land that previously was subject to ponding (Figures 6 and 8). Perhaps most important, a new channel has been excavated along the length of the cienega. This channel is straight, with a slightly concave profile and a trapezoidal cross section (Figures 9 and 10). Straightening the formerly braided channel has had the effect of increasing the stream gradient and, hence, discharge velocity. The concave profile, although not making the average gradient much greater than that of the natural channel, has eliminated the flat spots. The deepening of the channel has aided in the draining of the flat areas and the collection of water into the stock tanks. Construction of earthen dams in the tributary channels has also helped to alleviate ponding by retaining runoff in the upland areas and has halted the sedimentation that otherwise would occur downstream.

Eight earthen dams are located in the two channels containing ancient check dams near site USFS 06-04-109 (Figure 6). In at least two cases, these relatively recent features partially overlie their prehistoric counterparts. These check dams were built to retain runoff (see, e.g., Wanielista et al. 1984:147-50), probably during the 1930s (Heede 1960). A few large pinyon pines (*Pinus* *edulis*) growing through some dams indicate that, although they are technically modern, the earthen structures are not new. Excavation behind the dams appears to have been undertaken as part of construction. Sedimentation has not, however, occurred to any great extent, even though the ponds created by the check dams may be as much as fifty years old. Today, the dams provide water for cattle, and they further protect the cienegas from ponding, thereby improving pasturage. Although differences among modern ranching, tree-crop agriculture, and prehistoric agriculture are numerous, the methods used to alter the hydrology are similar and the intentions of the builders are identical. The check dams at site USFS 06-04-109 were designed and constructed to slow the velocity of water flowing onto the cienega lands, thereby alleviating ponding and sedimentation problems.

DISCUSSION

The existence of a highly sophisticated, yet simple, prehistoric water-control technology at site USFS 06-04-109 provides yet another example of the hydraulic competence of ancient people in the Southwest. As such, it invites comparison with other check dam sites in the region. The most logical candidates for comparison are the sites in the Point of Pines area. This area and its relict agricultural features are appropriate for three reasons. First, the Point of Pines environment is similar in many ways to that of site USFS 06-04-109. Second, Woodbury's (1961) research there is the most widely cited study of prehistoric agriculture in the Southwest. Third, although his assessment is the most systematic to date and his interpretations are generally accepted without question or qualifications, Woodbury himself acknowledged possible shortcomings and encouraged that future research be revisionary in nature: "For nearly every aspect of the subject more information would be helpful. The general statements . . . are, therefore, subject to future modification or refinement" (Woodbury 1961:35).

The check dams reported from Point of Pines have been interpreted as agricultural terraces. They are located across small, ephemeral channels that drain moderately sloping woodlands surrounding lower, relatively relief-free grasslands (Woodbury 1961:2). Stream gradients range from 5 to 21 percent (Woodbury 1961:12). The exact nature of the soils is unknown, but Woodbury (1961:3) described them as "sufficiently compact to prevent rapid penetration of moisture" and noted that "even a heavy downpour lasting 20 or 30 minutes will almost entirely run off."

The Point of Pines check dams themselves are similar to those at site USFS 06-04-109. They tend to be short, low, and spaced with no direct relationship to the nature and degree of slope (Woodbury 1961:12). The channels are not "terraced" to their maximum possible extent. The check dams also involve a very limited area, which is only a small percentage of the land available. The ten farm sites comprise only 30 ha scattered over an area of approximately 260 km^2 (Woodbury 1961:37, 2). Accepting that scores of other farm sites were not measured, mapped, or discussed, Woodbury (1961:37) suggested that as many as 400 ha may have been associated with stone alignments that have long since deteriorated. He also noted that several times this hectarage probably was farmed without leaving any traces that are discernible today (Woodbury 1961:42). Much of this land, 26,000 ha, is nonforested (Woodbury 1961:38) and, except in size, is similar to the cienega near site USFS 06-04-109.

Given their location and irregular spacing, the small size of the total area behind them, and the vast amount of grassland suitable for cultivation, it seems plausible that check dams at Point of Pines might have functioned not as terraces but as a means of altering the hydrology and facilitating agriculture on the grasslands. As they did at site USFS 06-04-109, the check dams could have prevented ponding and sedimentation on the grasslands, where slopes are less steep than on the surrounding woodlands which suffer severe runoff. Or they could have worked in conjunction with brush devices to allow practice of an "Akchin" type of runoff agriculture (Woodbury 1961:9-10). In either case, Woodbury (1961:12) himself acknowledged that an important function of check dams was to slow runoff. Interestingly enough, modern earthen dams not unlike those of site USFS 06-04-109 were also found in some Point of Pines drainages with ancient features (James A. Neely, personal communication). If we assume that the grasslands were cultivated, the check dams certainly would have protected those fields near the woodland-grassland ecotone where permanent habitation sites were located (Woodbury 1961:2). Fields in the grasslands but near the wooded slopes would also have been protected from excess runoff by the numerous linear borders that exist on adjacent hillsides (Woodbury 1961:12-13). These rock alignments are found in most of the small drainage areas. Together, the check dams and the linear borders are complementary and more effective in slowing runoff than either type of feature alone.

The purpose of this essay is not to refute the findings of Woodbury. If it were, fieldwork would have been conducted at Point of Pines. The features studied by Woodbury might well have been built as terraces; those at site USFS 06-04-109, however, appear not to have been. Evidence suggests they were constructed as true check dams, not terraces or erosion control devices. They were dams in the sense that they impounded water, albeit in small amounts and for brief periods. They literally "checked" the flow. The check dams at Point of Pines and other sites in the Southwest also might have been constructed for the purpose of protecting agricultural land downstream. Indeed, similar features have been found in ephemeral stream channels above several cienegas in the Pine Lawn Valley (personal observation; Harry J. Shafer, personal communication). This interpretation certainly merits more consideration than it has been given. Similarly, other interpretations need to be explored in more detail than they have been in the past. Many interpretations of check dam function rely heavily on ethnographic analogy. The universal applicability of ethnographically based explanations in the Southwest has, of course, come under considerable scrutiny (Cordell and Plog 1979), especially where agriculture is concerned (Woosley 1980; Sullivan 1982). The evidence from site USFS 06-04-109 suggests that a combined, systematic environmental and human-ecological assessment of each site is the most appropriate approach for understanding ancient agro-ecosystems.

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REFERENCES CITED

Alexander, B.G., F. Ronco, E. Fitzhugh, and J.A. Ludwig, 1984, A Classification of Forest Habitat Types of the Lincoln National Forest, New Mexico. Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-104. Fort Collins, Colo.

Anyon, R., and S.A. LeBlanc, 1980, The Architectural Evolution of Mogollon-Mimbres Communal Structures. The Kiva 45:253-77.

Ashbee, P., and I.W. Cornwall, 1961, An Experiment in Field Archaeology. Antiquity 35:129-34.

Barlett, P.F., 1980, Cost-Benefit Analysis: A Test of Alternative Methodologies. Pp. 137-60 in Agricultural Decision Making: Anthropological Contributions to Rural Development (ed. by P.F. Barlett). New York: Academic Press.

Betson, R.P., 1964, What is Watershed Runoff? Journal of Geophysical Research 69:1541-51.

Brady, N.C., 1974, The Nature and Properties of Soils. 8th ed. New York: MacMillan.

Briggs, D., 1977, Soils. London: Butterworth's.

Butzer, K.W., 1980, Context in Archaeology: An Alternative Perspective. Journal of Field Archaeology 7:417-22.

Butzer, K.W., 1982, Archaeology as Human Ecology: Method and Theory for a Contextual Approach. Cambridge, Eng.: Cambridge University Press.

Carter, G.F., 1945, Plant Geography and Culture History in the American Southwest. Viking Fund Publications in Anthropology 5.

Casselberry, S.E., 1974, Further Refinement of Formulae for Determining Population from Floor Area. World Archaeology 6:117-22.

Castetter, E.F., and W.H. Bell, 1942, Pima and Papago Indian Agriculture. Albuquerque: University of New Mexico Press.

Cordell, L.S., and F. Plog, 1979, Escaping the Confines of Normative Thought: A Reevaluation of Puebloan Prehistory. American Antiquity 44:405-29.

DiPeso, C.C., 1974, Casas Grandes: A Fallen Trading Center of the Gran Chichimeca, vol. 2. Dragoon, Ariz.: The Amerind Foundation.

DiPeso, C.C., 1984, The Structure of the 11th Century Casas Grandes Agricultural System. Pp. 261-69 in Prehistoric Agricultural Strategies in the Southwest (ed. by S.K. Fish and P.R. Fish). Arizona State University Anthropological Research Papers 33.

Donkin, R.A., 1979, Agricultural Terracing in the Aboriginal New World. Viking Fund Publications in Anthropology 56.

Doolittle, W.E., 1984, Agricultural Change as an Incremental Process. Annals of the Association of American Geographers 74:124-37.

Erasmus, C.J., 1965, Monument Building: Some Field Experiments. Southwestern Journal of Anthropology 21:277-301.

Fish, P.R., and S.K. Fish, 1984, Agricultural Maximization in the Sacred Mountains Basin, Central Arizona. Pp. 147-59 in Prehistoric Agricultural Strategies in the Southwest (ed. by S.K. Fish and P.R. Fish), Arizona State University Anthropological Research Papers 33.

Forde, C.D., 1931, Hopi Agriculture and Land Ownership. Journal of the Royal Anthropological Institute of Great Britain and Ireland 61:357-405.

Glassow, M.A., 1980, Prehistoric Agricultural Development in the Northern Southwest: A Study in Changing Patterns of Land Use. Ballena Press Anthropological Papers 16.

Golomb, B., and H.M. Eder, 1964, Landforms Made by Man. Landscape 14:4-7.

Hack, J.T., 1942, The Changing Physical Environment of the Hopi Indians of Arizona. Papers of the Peabody Museum of American Archaeology and Ethnology 35.

Hastorf, C.A., 1980, Changing Resource Use in Subsistence Agricultural Groups of the Prehistoric Mimbres River Valley, New Mexico. Pp. 79-120 in Modeling Change in Prehistoric Subsistence Economies (ed. by T.K. Earle and A.L. Christenson). New York: Academic Press.

Hayes, A.C., 1964, The Archaeological Survey of Wetherill Mesa, Mesa Verde National Park, Colorado. Washington, D.C.: National Park Service.

Hays, O.E., and V.J. Palmer, 1937, Soil and Water Conservation Investigations: Progress Report 1932-35. Upper Mississippi Soil Conservation Experiment Station. Washington, D.C.

Heede, B.H., 1960, A Study of Early Gully-Control Structures in the Colorado Front Range. Rocky Mountain Forest and Range Experiment Station, Paper 55. Fort Collins, Colo.

Henderson, F.M., 1966, Open Channel Flow. New York: MacMillan.

Hendrickson, D.A., and W.L. Minckley, 1984, Cienegas: Vanishing Climax Communities of the American Southwest. Desert Plants 6:131-75.

Herold, L.C., 1965, Trincheras and Physical Environment Along the Rio Gavilan, Chihuahua, Mexico. University of Denver Publications in Geography, Technical Paper 65-1.

Hill, J.N., 1970, Broken K. Pueblo. Anthropological Papers of the University of Arizona 18.

Horton, R.E., 1945, Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology. Bulletin of the Geological Society of America 56:275-370.

Houghton, F.E., 1983, Climate. Pp. 1-2 in Soil Survey of Grant County, New Mexico: Central and Southern Parts (by T.L. Parham, R. Paetzold, and C.E. Souders). United States Department of Agriculture, Soil Conservation Service, Forest Service, and New Mexico Agricultural Experiment Station. Washington, D.C.

Kirkby, M.J., and R.J. Chorley, 1967, Throughflow, Overland Flow and Erosion. Bulletin of the International Association of Scientific Hydrology 12:5-21.

Kirschmann, J.D., 1975, Nutrition Almanac. New York: McGraw-Hill.

Lawton, H.W., and P.J. Wilke, 1979, Ancient Agricultural Systems in Dry Regions.

Pp. 1-44 in Agriculture in Semi-Arid Environments (ed. by A.E. Hall, G.H. Cannell, and H.W. Lawton). New York: Springer-Verlag.

LeBlanc, S., 1971, An Addition to Naroll's Suggested Floor Area and Settlement Population Relationship. American Antiquity 36:210-11.

Leopold, L.B., and W.B. Bull, 1979, Base Level, Aggradation, and Grade. Proceedings of the American Philosophical Society 123:168-202.

Leung, W.W., 1961, Food Consumption Table for Use in Latin America. Bethesda, Md.: National Institute of Health.

Longacre, W.A., 1976, Population Dynamics at the Grasshopper Pueblo, Arizona. Pp. 169-84 in Demographic Anthropology (ed. by E.B.W. Zubrow). Albuquerque: University of New Mexico Press.

Manshard, W., 1974, Tropical Agriculture. London and New York: Longman.

Martin, P.S., J.B. Rinaldo, E.A. Bluhm, and H.C. Cutler, 1956, Higgins Flat Pueblo, Western New Mexico. Fieldiana: Anthropology 15.

Masse, W.B., 1979, An Intensive Survey of Prehistoric Dry Farming Systems Near Tumamoc Hill in Tucson, Arizona. The Kiva 45:141-86.

Morris, H.M., and J.M. Wiggert, 1972, Applied Hydraulics in Engineering. New York: John Wiley.

Mueller, J.E., 1972, Re-evaluation of the Relationship of Master Streams to Drainage Basins. Bulletin of the Geological Society of America 83:3471-74.

Nabhan, G., 1984, Soil Fertility Renewal and Water Harvesting in Sonoran Desert Agriculture: The Papago Example. Arid Lands Newsletter 20:20-28.

National Academy of Sciences, 1978, Postharvest Losses in Developing Countries. Washington, D.C.: National Research Council, National Academy of Sciences.

National Cooperative Soil Survey, 1976, Manzano Series. Unpub. ms. on file, U.S.D.A. Soil Conservation Service Office, Las Cruces, New Mexico.

Parham, T.L., R. Paetzold, and C.E. Souders, 1983, Soil Survey of Grant County, New Mexico: Central and Southern Parts. United States Department of Agriculture, Soil Conservation Service, Forest Service, and New Mexico Agricultural Experiment Station. Washington, D.C.

Pase, C.P., and D.E. Brown, 1982, Rocky Mountain (Petran) and Madrean Mountane Conifer Forests. Pp. 43-48 in Biotic Communities of the American Southwest-United States and Mexico (ed. by D.E. Brown). Desert Plants 4.

Patterson, T.C., 1963, Contemporaneity and Cross-Dating in Archaeological Interpretation. American Antiquity 28:389-92.

Plog, F., 1975, Demographic Studies in Southwestern Prehistory. Pp. 94-103 in Population Studies in Archaeological and Biological Anthropology: A Symposium (ed. by A.C. Swedlund). Memoirs of the Society for American Archaeology 30.

Plog, F.T., and C.K. Garrett, 1972, Explaining Variability in Prehistoric Southwestern Water Control Systems. Pp. 280-88 in Contemporary Archaeology: A Guide to Theory and Contributions (ed. by M.P. Leone). Carbondale and Edwardsville, Ill.: Southern Illinois University Press.

Poehlman, J.M., 1979, Breeding Field Crops. Westport, Conn.: AVI Publishing.

Rohn, A.H., 1963, Prehistoric Soil and Water Conservation on Chapin Mesa, Southwestern Colorado. American Antiquity 28:441-55.

Sandor, J.A., 1983, Soils at Prehistoric Agricultural Terracing Sites in New Mexico. Ph.D. diss., University of California, Berkeley.

Sauer, C.O., 1963, Early Relations of Man to Plants. Pp. 155-81 in Land and Life: A Selection from the Writings of Carl Ortwin Sauer (ed. by J. Leighly). Berkeley and Los Angeles: University of California Press.

Schacht, R.M., 1984, The Contemporaneity Problem. American Antiquity 49:678-95.

Schoenwetter, J., and A.E. Dittert, 1968, An Ecological Interpretation of Anasazi Settlement Patterns. Pp. 41-66 in Anthropological Archeology in the Americas (ed. by B.J. Meggers). Washington, D.C.: The Anthropological Society of Washington.

Schumm, S.A., and R.F. Hadley, 1957, Arroyos and the Semi-Arid Cycle of Erosion. American Journal of Science 255:161-74.

Schwab, G.O., R.K. Frevert, T.W. Edminster, and K.K. Barnes, 1981, Soil and Water Conservation Engineering. New York: John Wiley.

Shanan, L., 1974, Rainfall and Runoff Relationships in Small Watersheds in the Avdat Region of the Negev Desert Highlands. Ph.D. diss., Hebrew University of Jerusalem.

Staten, G., D.R. Burnham, and J. Carter, 1939, Corn Investigations in New Mexico. New Mexico College of Agriculture and Mechanical Experimental Station, Bulletin 160.

Stewart, G.R., and M. Donnelly, 1943, Soil and Water Economy in the Pueblo Southwest: II. Evaluation of Primitive Methods of Conservation. Scientific Monthly 56:134-44.

Sullivan, A.P., 1982, Mogollon Agrarian Ecology. The Kiva 48:1-15.

Tadmor, N.H., L. Shanan, and M. Evenari, 1960, The Ancient Desert Agriculture of the Negev: VI. The Ratio of Catchment to Cultivated Area. Ktavim (Israel Journal of Agricultural Research) 10:193-221.

Thorne, D.W., 1979, Crop Characteristics and Cropping Systems. Pp. 117-35 in Soil, Water and Crop Production (ed. by D.W. Thorne and M.B. Thorne). Westport, Conn.: AVI Publishing.

Turnage, W.V., and T.D. Mallery, 1941, An Analysis of Rainfall in the Sonoran Desert and Adjacent Territory. Carnegie Institution of Washington, Publication 529.

Turner, B.L., II, and W.E. Doolittle, 1978, The Concept and Measure of Agricultural Intensity. The Professional Geographer 30:297-301.

United Nations, 1961, Earthmoving by Manual Labour. United Nations Economic Commission for Asia and the Far East, Working Party on Earth-moving Operations.

Vivian, R.G., 1974, Conservation and Diversion: Water-Control Systems in the Anasazi Southwest. Pp. 95-112 in Irrigation's Impact on Society (ed. by T.E. Downing and M. Gibson). Anthropological Papers of the University of Arizona 25.

Wanielista, M.P., Y.P. Yousef, J.S. Taylor, and C.D. Cooper, 1984, Engineering and the Environment. Monterey, Calif.: Brook-Cole.

Wertz, J.B., 1966, The Flood Cycle of Ephemeral Mountain Streams in the Southwestern United States. Annals of the Association of American Geographers 56:598-633.

Wheeler, D.A., 1979, The Overall Shape of Longitudinal Profiles of Streams. Pp. 241-60 in Geographical Approaches to Fluvial Processes (ed. by A.F. Pitty). Norwich, Conn.: Geobooks.

Wilcock, D.N., 1971, Investigation into the Relations between Bedload Transport and Channel Shape. Bulletin of the Geological Society of America 82:2159-76.

Winter, J.C., 1974, Aboriginal Agriculture in the Southwest and Great Basin. Ph.D. diss., University of Utah.

Woodbury, R.B., 1961, Prehistoric Agriculture at Point of Pines, Arizona. Memoirs of the Society for American Archaeology 17.

Woosley, A.I., 1980, Agricultural Diversity in the Prehistoric Southwest. The Kiva 45:317-35.