Native American methods for conservation and restoration of semiarid ephemeral streams

J.B. Norton, F. Bowannie Jr., P. Peynetsa, W. Quandelacy, and S.F. Siebert

ABSTRACT: Combined effects of brush encroachment and channel entrenchment in the Southwestern United States threaten ecological, hydrological, and agricultural functions of ephemeral streams and associated alluvial surfaces. Restoration is difficult because entrenchment is widespread, and highly variable flow magnitudes defy standardized structural approaches. Methods developed by the Zuni Indians during more than 2,000 years of farming on dynamic alluvial fans combine brush removal with ephemeral channel-erosion control and show promise for effective watershed-scale conservation and restoration. Zuni utilize several types of simple brush structures that rely on hydraulic characteristics of woody material to modify erosive and depositional effects of both small seasonal and irregular storm-flow events. Zuni brush structures are inexpensive and quick to build, require no external material inputs, and avoid the extensive disturbance associated with conventional rigid check-dam construction. Successive surveys at three incised-headwater ephemeral channels on the Zuni Indian Reservation showed that Zuni techniques increased the incidence of overbank flow during small streamflow events (acting as permeable check dams) and large floods (moving downstream and forming debris jams) and thereby helped reconnect channels to alluvial fans. Zuni brush structures represent a potential alternative to capital- and labor-intensive approaches to semiarid watershed conservation and restoration.

Keywords: Arroyo cutting, conservation farming, discontinuous ephemeral streams, ecological restoration, local knowledge, permeable check dams, runoff agriculture, woody debris, woody species encroachment

Arroyo cutting and encroachment by woody species have been degrading desert and shrub-steppe grasslands of the Western United States for more than 100 years (Archer 1994; Bryan 1925). Although the two processes are closely related because woody species encroachment increases runoff and erosion (Abrahams et al. 1995; Bull 1997), they are typically treated separately in rangeland conservation and restoration efforts. A comprehensive approach that restores both plant communities and surface hydrology to more desirable conditions could improve the success and cost-effectiveness of ecological restoration efforts. This paper explores traditional Zuni methods that use brush and trees cleared from degraded rangelands to control arroyo cutting. It also presents an example in which local knowledge in danger of being lost because of drastic declines in traditional land use could be valuable in addressing a complex, contemporary environmental problem.

Large-scale gully erosion, which severs connections between ephemeral streamflow and ecologically important alluvial landforms, has defied control for decades (Gellis et al. 1995). Conventional approaches, including rigid impervious check dams made of earth, concrete, gabions, or logs (Heede 1976;
unpredictable landscape process that has been monitored (or arroyo cutting) is a dynamic, variable and unpredictable conditions, a characteristic that is increasingly sought in modern management systems (Berkes et al. 1998; Tabor 1995). In the Southwestern United States, ephemeral stream entrenchment (or arroyo cutting) is a dynamic, unpredictable landscape process that has been managed by indigenous farmers who have a very rich body of traditional knowledge.

Controlling entrenchment of semiarid ephemeral streams is difficult because the extremely variable and dynamic conditions create stream behavior different from that where most hydrological principles and erosion control methods were developed (Bull 1997). Small streamflow events that occur once every two to 10 years carry most of the sediment that fills and destroys structures built to store water and control large floods. Large, powerful floods can breach, flank, or undercut check dams designed to control erosion during smaller flows (Gellis et al. 1995).

Though conventional rigid check dams can modify particular stream reaches (Gellis et al. 1995), the immense extent of ephemeral drainage networks and relatively high cost of such structures limit their watershed-scale effectiveness. Soil bioengineering approaches (Gray and Sotir 1996) are also relatively material- and labor-intensive for such extensive application, and soil conditions of semiarid ephemeral streams where arroyo cutting is most prevalent may be too dry to support fast-growing vegetation. Headwater streams often make up as much as 85% of the total channel length in watersheds (Peterson et al. 2001) and, in semiarid areas, flow only in response to rainfall. Large watershed restoration efforts must be simple and quick to implement, require minimal capital and labor inputs, and effectively modify both small flows and powerful floods.

Zuni farmers who still practice traditional agriculture use simple, low-investment structures that appear to mitigate destructive arroyo cutting during both small and large streamflows. This type of erosion control is often part of brush- and tree-clearing activities intended to prepare fields for cultivation or to improve livestock grazing lands. Our objective was to describe and evaluate the performance of indigenous erosion control methods and to evaluate their potential application in watershed- and ecosystem-scale conservation and restoration efforts.

Methods and Materials

We conducted this study in collaboration with traditional Zuni farmers on the Zuni Indian Reservation in west-central New Mexico. The Zuni reservation lies on the southeastern part of the Colorado Plateau at 1,800 to 2,400 m elevation and receives an average of 300 mm of precipitation annually, the majority of which often falls during thunderstorms in July, August, and September. The combination of steep erodible sandstone and shale slopes covered by patchy pinyon-juniper (Pinus edulis-juniperus spp.) and scrub-shrub plant communities with relatively intense summer storms contributes to dynamic, sand-bed fluvial systems that move large amounts of sediment (Lagasse et al. 1990). Zuni subsistence agriculture depended on corn (Zia mays) grown in nonirrigated fields in these dynamic fluvial settings for more than 1,500 years (Kintigh 1985). Socio-economic change and assimilation policies beginning with U.S. occupation of Zuni lands in the mid-19th century caused drastic declines in agriculture (Cleveland et al. 1995). Major arroyo cutting coincided with this shift away from traditional farming and led to multiple, U.S.-sponsored erosion-control efforts throughout the 20th century, including large earthen check dams built by government agencies and smaller-scale efforts by the Civilian Conservation Corps (CCC) and other programs (Gellis et al. 1995).

Three actively eroding, low-gradient, entrenched, meandering headwater ephemeral streams—Rosgen “F-type” channels (Rosgen 1994)—were selected for treatment with traditional Zuni brush structures (Laate, Lalo, and Quandelacy sites). These streams are representative of headwater alluvial systems and provide important ecological, hydrological, and agricultural functions.

The Laate site is a short ephemeral channel that crosses an orchard high on the leeward side of a sandstone mesa. The channel gradient was historically maintained to facilitate flooding of the sandy eolian soils. In 1996, channel incision threatened to exclude both mature and recently established fruit trees from streamflows. The Quandelacy site is a continuously incised channel running from the mouth of a small canyon through range-lands dominated by big sagebrush (Artemisia tridentata). At the beginning of our study, this channel ranged from a slot-like gully about 1 m deep by 1 m wide to a 6 m deep, V-shaped arroyo and had several steep headcuts. The Lalo site is a deeply incised arroyo that empties onto a traditional, hand-cultivated cornfield. By 1998, the arroyo had deepened for a third of the way into the cornfield, excluding about three-quarters of the field from flooding. A continuous riff had formed through the field.
A three-part approach for treating and evaluating structure effectiveness was implemented at each study site:

**Treatments.** Zuni crews led by people with lifelong experience in traditional agricultural practices installed erosion-control structures at the three sites using axes, shovels, and post-hole diggers. The Laate site was first treated in June 1996, the Lalio site in June 1998, and the Quandelacy site in June 1999. Members of the crews recorded labor input, wrote descriptions of structures, sketched maps and structure designs, and photographed construction. The crew leaders are co-authors of this report.

**Channel morphology.** Successive longitudinal thalweg surveys were used to document treatment effects on channel morphology (Harrelson et al. 1994). Surveys were conducted during construction, after flow events, and at the end of the study. (The relatively remote Laate site was surveyed only at the beginning and end of the study period.) Photo points were established along each channel. Surveys included elevations of thalweg, structures, banks, and water levels identified by high-water marks on the arroyo banks.

**Channel/alluvial fan connectivity.** Pre- and post-study channel dimensions were used to estimate the probability of overbank flow at the Lalio and Quandelacy sites. Manning’s equation was used to estimate the peak discharge that would be required to overtop pre- and post-study arroyo banks and then was applied to two- through 100-year recurrence interval equations (Thomas et al. 1997) to estimate the average frequency that such overbank flows would occur.

To place the events and treatment effects observed in 1999 within the context of long-term Zuni climate, recurrence intervals of both rainfall and streamflow events were estimated. Rainfall volume and intensity were monitored at a tipping-bucket rain gauge 2 km from the Lalio site (data courtesy of the Zuni Conservation Project, Zuni Pueblo, New Mexico) and rainfall-event recurrence intervals were determined with intensity-duration-frequency curves for Albuquerque, New Mexico (USWB 1955). The magnitude of 1999 streamflow events was determined by applying Manning’s equation to channel dimensions surveyed after flow events by using high-water marks to indicate peak stage. These values were compared to peak discharges derived from equations for two- through 100-year recurrence interval events in the two watersheds (Thomas et al. 1997).

**Results and Discussion.**

Traditional Zuni brush treatments effectively reduced the erosive power of small streamflow events and large floods, though by very different modes of action. They also effectively modified channel morphology and restored channel/alluvial fan connectivity. During small flows, the structures acted as permeable barriers that retained runoff in temporary pools and accumulated sediments. During larger, more powerful floods, many of the structures were destroyed, but the woody debris was redeposited in debris jams that altered channel morphology and drastically increased the likelihood of overbank flow.

**Treatment Design and Labor Requirements.** The workers installed four general types of brush structures throughout the treated reaches. Construction followed general principals from knowledge about flow events but varied by worker and by streamflow situation. Spacing between the structures (Figure 1) averaged less than 20 m for all the sites, much closer than guidelines calculated with Heede’s (1976) spacing rule, which is commonly used for designing erosion-control projects. This spacing rule is based on the equation:

\[ S = \frac{H}{K G \cos \alpha} \]

where \( S \) is spacing (m), \( H \) is dam height (m), \( G \) is the channel gradient ratio, \( \alpha \) is the angle corresponding to the channel gradient (\( G = \tan \alpha \)), and \( K \) is a constant developed through regression analyses for different channel gradients (\( K = 0.3 \) for \( G \leq 0.20 \)).

The exact placement of the brush structures varied depending upon channel characteristics and the types of woody material most readily available. Simple brush piles were the most commonly employed technique throughout the channels, with stronger structures placed in key locations toward distal ends of the channels and in constricted areas. Minimizing disturbance to channel beds and banks, using material close at hand, and using stones only sparingly to compress brush were concepts common to all four kinds of structures, which are described below:

**Brush piles.** Limbs of pinyon and juniper trees and whole, big sagebrush plants were piled in channels with larger stems pointing downstream (Figure 2a). Material was stomped down repeatedly and layered sparingly with stones or larger logs where those were readily available. Large amounts of sagebrush were packed into slot-like channels over distances of as much as 30 m by stomping down layer after layer. Shallow rills through the Laate Orchard and the Lalio cornfield were filled with fine woody material from rubber rabbitbrush (Chrysothamnus nauseosus) and broom snakeweed (Gutierrezia sarothrae). This was the most rapid method and had the objective of placing as much debris as possible into the channel with a minimum of additional strengthening.
Figure 2
Types of structures installed at study sites: (a) brush pile with fine branches oriented upstream and stones to compress brush (drawing by Fred Bowannie Jr.); (b) brush check dam with fine branches woven into larger limbs piled across channel. (Tape follows thalweg.); (c) pungie posts immediately upstream from a post-and-wire structure. Posts are about 8 cm in diameter at the base.

Check dams. Simple check dams of interwoven woody material were slightly more intensive than the brush piles. In this approach, the largest, longest limbs were laid across the channel in a pile about 0.5 to 1 m high with brushy tops in alternating directions. Smaller limbs were jabbed and woven into the pile so that branches and leaves presented a dense mat of fine woody material to the upstream direction (Figure 2b). Some of these dams were reinforced with posts cut from pinyon or juniper stems and set immediately downstream from the brush structure.

Post-and-wire methods. In this method, workers set two rows of poles about 1 m apart across the arroyo channel and packed brushy material between the poles to create a barrier about 1.5 m high. The tops of the poles were then wired together. This method required more effort in sorting and trimming woody material, setting posts, packing brush, and wiring braces together. This method was deliberately employed in relatively wide, low-energy reaches, at points immediately below sharp bends, or in series of two to three structures. Each of these structures was built by one worker and took two to three hours for structures up to 7 m long.

Pungie posts. Pungie posts consist of clusters of pinyon and juniper limbs and stems set into the arroyo bed to form comb-like structures that capture woody debris and create reinforced debris jams during flow events (Figure 2c). The posts were set at least 60 cm into the ground, angled upstream. Placement was downstream from brush-pile structures and upstream from other types to protect and reinforce them. Some of the pungs were reinforced with post-and-wire braces. Part way through the season, the workers decided to alter this method by leaving fine branches on the posts so that, if posts washed out, they would function as woody debris.

The crew treated a total of 1.25 km of ephemeral stream channel during the study period but had to treat segments repeatedly after large floods removed structures three times at the Lalio site and once at the Quandelacy site. Including the repeated treatments, 3.4 km were treated, averaging 93 person-hours km⁻¹ of channel. The first treatments at the Lalio and Quandelacy sites were relatively rapid, but the second treatments required more time to build the reinforced pungie post and post-and-wire structures.

Treatment Effects. Although 1999 was a relatively dry year (252 mm, or 80% of normal precipitation), 170 mm of rain fell in July and August, which is 159% of normal precipitation (WRCC 2001). Much of this rain came as unusually intense thunderstorms (Figure 3), including a greater-than-25-year recurrence interval storm on July 5, at more than 18 mm in 15 minutes. The thunderstorms generated streamflow events with widely varying magnitude, including several five- to 25-year recurrence interval flows and four that equaled or exceeded 100-year flood events (one at the Quandelacy site on Aug. 2 and three at the Lalio site on July 5, Aug. 2, and Aug. 27), according to measurements conducted by hydrologists of the Zuni Conservation Project. Because of the remote nature of the Laate site, channel dimensions were surveyed only during treatment installation and at the end of the study, so flow magnitudes were not estimated for that site.

The structures at the Quandelacy and Lalio sites all withstood the less-than-25-year recurrence interval flows, temporarily retaining water and causing some sediment deposition (Figures 4 and 5). During larger floods, however, many of the structures washed out.
deposition for more than 100 m upstream. Channels upstream from the debris jams filled with sediment to within a few centimeters of the bank from pretreatment depths of about 1.5 m at the Lalio site (Figure 6) and 1 m at the Quandelacy site. This caused overbank flow for nearly 100 m upstream of the debris jam at the Lalio site, which deposited nearly 20 cm of sand on parts of the alluvial fan. Figure 7 shows the pre- and post-study channel profiles at the three study sites. The structures at the Laate site retained sediment and were mostly buried during the post-treatment survey, except for the most distal structure, which had been installed on bedrock and washed away.

The overall effect of the treatments was to restore flooding to larger portions of the alluvial fans at all three sites. The schematic map of the Lalio site (Figure 8) shows that, at the beginning of the study, flows emerged from the channel near the center of the agricultural field. The apex of the fan, or the point where flow leaves the channel and spreads over the alluvial fan, moved upstream after each flood as the channel filled with sediment. At the end of the study, small flows (~ two- to five-year recurrence interval) remained in the channel and flowed to the agricultural field, but larger, potentially destructive floods would overtop the banks far upstream. Although the response of vegetation in the areas cleared for brush was not measured, increased grass production, particularly blue gram (Bouteloua gracilis), was evident compared with adjacent areas.

Repeated surveys at channel cross-sections at the Lalio and Quandelacy sites confirm that connectivity between the ephemeral stream channels and alluvial fans was restored (Table 1). At the Lalio site, sediment deposition 100 m upstream from the debris jam reduced the hydraulic radius so that calculated recurrence interval (Thomas 1997) of overbank flow changed from nearly 50,000 years at the beginning of the study to four years at the end. Similarly, at the Quandelacy site, calculated recurrence interval of overbank flow changed from 3,000 years to three years.

**Literature Review and Discussion.** Clearing brush and trees from rangelands and using the material for erosion control simultaneously addresses two major ecological degradation processes. Clearing brush and trees that compete with grasses is a common approach to ecological restoration and has been shown to
increase forage production (Archer 1994). Increased herbaceous ground cover also increases the hydraulic roughness of soil surfaces, causing more infiltration and less runoff (Bull 1997). The Zuni workers often pruned lower branches on pinyon and juniper trees rather than cutting whole trees, explaining that removing lower branches increased forage production around trees and increased site distances for livestock herding but maintained the shade and wind protection provided by the trees. Pruning and/or clearing trees and brush is often the principal purpose; the materials are disposed of in arroyos to control erosion.

Our results are supported by a previous study on the Zuni Indian Reservation in which Gellis et al. (1995) found that 28 of 47 large, heavy-equipment-built earth and rock erosion-control structures they evaluated had breached, and 31 were more than half-filled with sediment in the 20 to 30 years since construction. In contrast, only five of 23 brush structures had washed out or were breached, while the remaining structures continued to function. The brush structures were built in the 1970s by a Youth Conservation Corps team led by an elderly Zuni farmer. Gellis et al. (1995) attributed failures of both the large rock and earthen structures to lack of maintenance. Because they require no heavy earth-moving equipment or offsite materials, the brush structures would be easier and less expensive for local people to build and maintain. Unlike capital- and labor-intensive rigid dams, modification of Zuni brush structures by streamflow events is not considered failure of the structures but part of the ongoing process of conserving alluvial fan functions.

In this traditional Zuni approach, as much woody material as possible is placed in channels with minimal strengthening. No keys into beds or banks and no reinforcements with stones or gabions are used. Instead of relying on rigid check dams, which can cause scouring of streambeds or banks (Gellis et al. 1995), erosion control is achieved through hydraulic characteristics of woody material. Although there are few published accounts of permeable brush structures for controlling arroyo cutting, woody debris is commonly used to improve or restore aquatic habitat in perennial streams.

Studies of woody debris suggest that the Zuni methods could be effective for increasing sedimentation. Woody debris is responsible for as much as 87% of channel sediment storage in small woodland streams, with 39% or more of the individual pieces forming depositional sites (Fetherston et al. 1995). As such, woody debris is a primary determinant of channel morphology, forming pools and regulating transport of sediment, organic matter, and nutrients. While lack of woody debris is often recognized as a characteristic of dryland streams, Minckley and Rinne (1985) suggest that streamside vegetation was abundant before destruction of riparian forests.
In one study, woody debris covered less than 2% of the streambed but provided 50% of total flow resistance (Mangia and Kirchner 2000). After initial treatments in our study, woody material covered nearly 50% of the channel bed of the treated reaches.

Implications for Watershed Restoration.

The labor and materials required to construct brush piles suggest that this method could be implemented rapidly and inexpensively over entire watersheds. At an average of 93 person-hours km\(^{-1}\) of entrenched channel treated, a 20-person crew could treat more than 1.7 km per eight-hour day. Our work during an unusually wet and stormy year required that we treat the study reaches repeatedly after 50- to 100-year recurrence events. These unusually frequent and high magnitude storm flows came almost immediately after structures were installed, before smaller events began to bury the woody material with sediments and hold them in place. This partly explains the need to repeatedly treat the reaches.

Over the long term and across whole watersheds, treated headwater channels may need additional woody material added at about 20-year intervals, after large floods remove woody debris or as brush dams fill with sediment. This observation is supported by Gellis et al. (1995), who found that five of 28 brush structures needed maintenance 20 years after installation. More frequent debris additions after flows that cause sedimentation would raise channel-bed elevations and thereby increase the likelihood of overbank flows and deposition in agricultural fields.

These Zuni erosion control practices are closely associated with traditional rainfed corn (Zea mays) farming, which provided the basis of Zuni subsistence until the late 19th century (Kintigh 1985). Since then, changing socio-economic conditions, devastating epidemics, and U.S. agricultural development policies caused drastic declines in rainfed farming (Cleveland et al. 1995; Ferguson and Hart 1985). The cessation of traditional farming in ephemeral stream courses coincided with the onset of stream-channel incision at Zuni (Balling and Wells 1990; Bryan 1925). This suggests that the absence of previously widespread traditional erosion-control activities may have contributed to the severity of channel entrenchment that is now widespread in the Zuni area.

The Zuni approach to controlling arroyo...
cutting may be relevant to large-scale rangeland watershed restoration in the Western United States. Implementing this approach could be as simple as using woody material displaced during chaining or cutting to build the simple permeable brush check dams in nearby incised watercourses. While this additional work would be relatively inexpensive, it could effectively reduce erosion and increase sedimentation over wide areas.

The Zuni methods could be useful in other semiarid regions where incised ephemeral stream channels have sand or finer beds, flow events move large amounts of bed load and suspended sediments, and there is abundant fine woody material near eroding channels. An important characteristic of the Zuni approach is that farmers modify erosion control methods to fit particular situations (i.e., channel geometry or the types of woody material available) or objectives (i.e., control, prevention, or restoration of connectivity between channels and surrounding alluvial surfaces). As such, the Zuni methods would probably be most applicable if built upon local environmental knowledge and traditions. Traditional, low-input erosion-control practices are widely used throughout the world (e.g., Mexico, Bocco 1991; and Indonesia, Siebert and Belsky 1990) and typically display adaptations to local environmental and cultural conditions, as well as basic principles of potential use elsewhere.

Summary and Conclusion

Traditional Zuni erosion-control methods effectively modify channel morphology of entrenched headwater ephemeral streams after small flows and powerful floods in ways that increase the occurrence of overbank flows and the area of alluvial fans flooded by recurrence interval flows of less than or equal to five years. Frequent, low-intensity floods are important to renewal of desirable soil properties. These methods are rapid and inexpensive to implement and thus may be useful in watershed-scale restoration efforts. While most conventional erosion-control methods rely on rigid check dams of concrete, stones, gabions, and/or logs keyed into streambeds and banks, the Zuni brush structures rely on hydraulic characteristics of woody debris to modify erosive flows. Rather than investing time in strengthening structures, Zuni farmers and livestock herders focus on placing as much woody material as possible over long channel reaches in an attempt to reduce flood power, move fan apexes upstream, and increase the frequency and area of overbank flows. The Zuni methods combine clearing brush and trees with erosion control in an efficient, comprehensive approach to watershed restoration.

The approach described herein is based on long-term understanding of the range of variability in the dynamic fluvial environ-

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Table 1. Estimated discharge for overbank flow (discharge required to reach top of channel banks calculated using Manning's equation with channel dimensions at the beginning and end of the study period. See discussion in text.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Lalio overbank, pretreatment</th>
<th>Lalio overbank, post-treatment</th>
<th>Quandelacy overbank, pretreatment</th>
<th>Quandelacy overbank, post-treatment</th>
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<td>36</td>
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* Meters from lower end of longitudinal profile.

** Based on roughness coefficients for sand bed channels (Jarrett 1985).

*** Estimated using regression equations of Thomas (1997).
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