Influences of Alluvial Fans on Upland Watersheds in Central Nevada

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Abstract

Geomorphic, hydrologic, and vegetation processes of upland watersheds in central Nevada are influenced by side-valley alluvial fans. Discontinuous longitudinal stream profiles and spatial variation in stream channel incision are often associated with the alluvial fans. In many cases, groundwater flow is restricted immediately upstream of side-valley fans resulting in elevated water tables and the occurrence of springs and seeps. Riparian vegetation patterns are influenced both longitudinally and laterally with respect to the stream channel, and large meadow complexes often occur upstream of side-valley fans. Restoration and appropriate management of these watersheds requires knowledge of the history and influence of side-valley fans.

Keywords: alluvial fans, riparian vegetation, stream morphology, groundwater, Great Basin

Introduction

Side-valley alluvial fans ("tributary junction fans" in Meyer et al. 2001) influence stream morphology, groundwater hydrology, and riparian vegetation composition. Here we examine the influence of side-valley fans on these watershed characteristics in central Nevada, drawing primarily upon research conducted within the Great Basin Ecosystem Management Project (GBEMP) over the past 10 years. We define a side-valley fan as one that occurs at the mouth of a tributary drainage (usually ephemeral) and lies on or, in some cases, completely across the valley floor of an axial stream (usually perennial). Considerable literature exists regarding the characteristics and formative processes of alluvial fans (e.g., Bull 1977, Blair and MacPherson 1994), but much of this effort has focused on terminal or "mountain edge" alluvial fans. Less is known about the valley segment or riparian corridor scale effects of alluvial fans occurring within montane watersheds. We present here a summary of fan-related research conducted by the GBEMP and its cooperators in upland watersheds of central Nevada.

Study Area

Most of the research discussed in this paper was conducted in Kingston, Big, Washington, Cottonwood, and San Juan Creeks, on the Humboldt-Toiyabe National Forest, in central Nevada's Toiyabe Range (Figure 1).

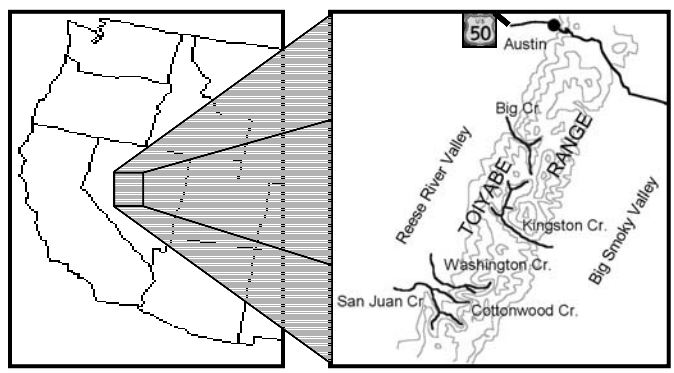

Figure 1. Study area, central Nevada, on the Humboldt-Toiyabe National Forest.

This mountain range, in the basin and range physiographic province of western North America, exceeds 3300 m in height and is bounded on the east and west by intermontane valleys of 1800-1900 m elevation. The climate is semiarid with annual moisture varying with altitude from 25-60 cm (USDA Forest Service unpublished data). The streams are high-gradient, low-flow (0.015 to 0.063 m^3/s base flow) systems with low sediment loads. They flow through valley fill derived primarily from volcanic rocks, although some drainages have a

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significant amount of sedimentary lithology (Kleinhampl and Ziony 1985).
Upland vegetation consists of sagebrush-grass, pinyon-juniper, and mountain brush communities. Riparian vegetation includes woody species (e.g., *Salix* spp., *Betula occidentalis, Populus tremuloides*, *Rosa woodsii, Artemisia tridentata* ssp. *tridentata,* and other shrubs), sedges and rushes (e.g., *Carex nebrascensis, C. rostrata, C. douglasii,* and *Juncus balticus*), grasses (e.g., *Deschampsia cespitosa, Poa pratensis,* and *P. secunda*), and a number of forbs.

Geomorphic Effects

Benda (1990) and Wohl and Pearthree (1991) investigated side-valley fans formed during storm events in humid and semi-arid regions, respectively. They found that debris fans could temporarily block the axial (trunk) stream, causing ponding and accumulation of a lens of sediment immediately upstream of the fan. Upstream deposits were subject to incision when, days or weeks later, the axial stream breached and subsequently removed all or part of the debris fan. Leeder and Mack (2001) documented this phenomenon ("toe cutting"), which is governed by axial stream power.

Geomorphic effects of side-valley alluvial fans in the upland watersheds of the Great Basin were investigated by Miller et al. (2001). They determined that hillslope erosion and consequent valley bottom and side-valley fan aggradation occurred 2500-1900 years ago as a result of a climate shift from a cool-wet period (the "Neoglacial") to a dry-warm regime. Fans prograding completely across the valley floor temporarily blocked downstream transport of the axial streams' sediment load, resulting in sediment accumulation and local moderation of stream slope. As a consequence of the hillslope erosion and a depletion of available sediments, the stream systems are currently sediment limited and exhibit a natural tendency to incise. In contrast to the above studies, the degree to which the fan deposits have incised depends largely on basin sensitivity to natural and anthropogenic disturbance as governed by factors such as basin geology and morphometry, hydrologic attributes, and sediment storage characteristics (Germanoski and Miller 2003). Watersheds in which the fans are largely incised are underlain primarily by Tertiary volcanic rocks, have large, high relief basins and relatively high stream power. The channels have longitudinal profiles that are relatively smooth, and a high number of semi-continuous terraces. Watersheds in which few of the fans are incised are underlain primarily by sedimentary and meta-sedimentary rocks, are generally less rugged, have lower relief and exhibit lower relative stream power than watersheds in which the fans are largely incised. The fans in these watersheds result in unstable longitudinal profiles that are relatively flat upstream of the fans and significantly steeper where the channels traverse the fans (Figure 2). Relatively coarse alluvium associated with the fans has slowed or prevented incision through many of the fans to date, but the oversteepened segments are inherently unstable.

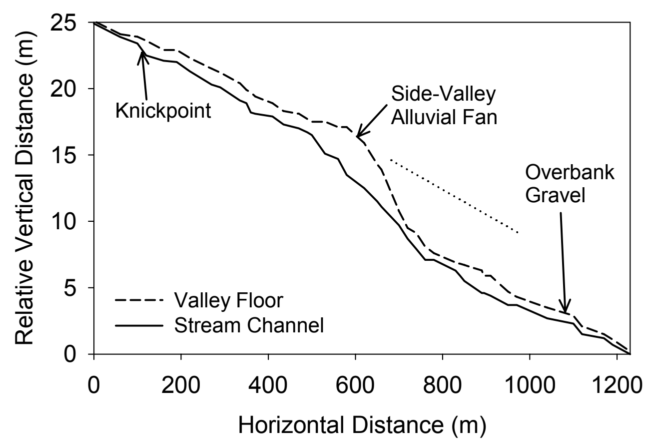

Figure 2. Typical longitudinal profile of an axial stream influenced by side-valley alluvial fans (modified from Miller et al. 2001).

In those basins with relatively unincised fans, Miller et al. (2001) indicated that fans act as local base-level controls, contributing coarse-textured materials to the stream channel in reaches immediately below fans. Channel incision varies as a function of downstream distance from a side-valley fan, with greatest incision occurring where the stream traverses the fan toe, and overbank gravel deposition occasionally taking place immediately above fans. Davis (2000) studied this characteristic in detail, and found that reaches above coarse-textured fans exhibited relatively finer channel particles, little channel incision, and significantly less steep stream slopes than reaches adjacent to alluvial fans. These trends generally were not present for reaches coincident with fans composed of finer-textured materials.

Davis (2000) and Korfmacher (2001) both found that valley floor morphology can be affected by side-valley alluvial fans. Generally, above-fan locations have broad, flat (in the direction perpendicular to the stream) valley floors; below-fan locations had narrower valley floors; in at-fan locations, where recognizable valley floors existed, they were both narrower and more steeply sloped valley floors (Table 1).

Table 1. Valley morphological characteristics by fan position for 53 locations in Big, Kingston, Washington, Cottonwood, and San Juan Creeks, central Nevada. Values are mean +/- standard errors (modified from Korfmacher 2001).

Fan Position	**Floor Slope (m/m)**	**Width (m)**
Above	0.0353 ± 0.0035	67.7 ± 5.0
At	0.1193 ± 0.0157	21.0 ± 4.0
Below	0.0365 ± 0.0085	54.3 ± 4.0

Hydrologic Characteristics

Alluvial fans influence hydrogeologic characteristics both within individual fans and at a broader, stream segment scale. Hydrologic characteristics of alluvial fans are important determinants of riparian vegetation community composition (Miller et al. 2001, Chambers et al. 2003) and comprise the link between geomorphic phenomena within a stream system and riparian plant ecological processes and dynamics. Alluvial fans in central Nevada are typically composed of weakly bedded material of varying textures, deposited in units corresponding to climate changes (Ritter et al. 2000, Miller et al. 2001). Hydrologic characteristics of the fans are therefore spatially and seasonally variable, as are the fans' effects on the adjacent riparian zones. Jewett et al. (2003) studied the hydrologic characteristics of a fan-influenced site at Big Creek in central Nevada's Toiyabe Range (Figure 3), using a series of piezometers and observations wells to assess horizontal hydraulic gradients, and nested piezometers to assess vertical gradients. Side-valley fans play several roles in the groundwater characteristics at the study site. They provide a subsurface conduit for groundwater input, influence groundwater depths and hence groundwater availability, and govern groundwater input to the stream.

In the uppermost area of the study site ("A", Figure 3), a small side-valley fan grades out from a tributary watershed. Groundwater recharge from the stream is the dominant feature of the subsurface hydrology in this part of the study site. During the wet season, lateral groundwater flow from the stream occurs and the stream is characterized as a losing reach. However, this characteristic is seasonal. In the summer (dry season) lateral groundwater flow is minimal, although vertical (downward) and down-valley groundwater flow continues throughout the year. The water table on the fan itself is deep (generally 2-3 m). Just downstream of this fan ("B", Figure 3), the water table is shallower, varying seasonally between surface flow and 30-40 cm depth. Further downstream at the lower end of the study site ("C", Figure 3), a larger side-valley fan constricts the stream. This fan influences groundwater flow patterns by restricting the area through which the groundwater may pass. This phenomenon, in concert with the effect of a local bedrock high (Jewett et al. 2003), forces groundwater closer to the surface and produces above-surface flow just upstream of this fan. The riparian zone contains a number of small springs and seeps in this area that remain active throughout the year. Depth to groundwater is shallow with above-surface flow present. The stream is characterized as a gaining reach throughout the year. The vertical hydraulic gradient in this area is predominantly upward, and was continuously upward in a wet year (1998).

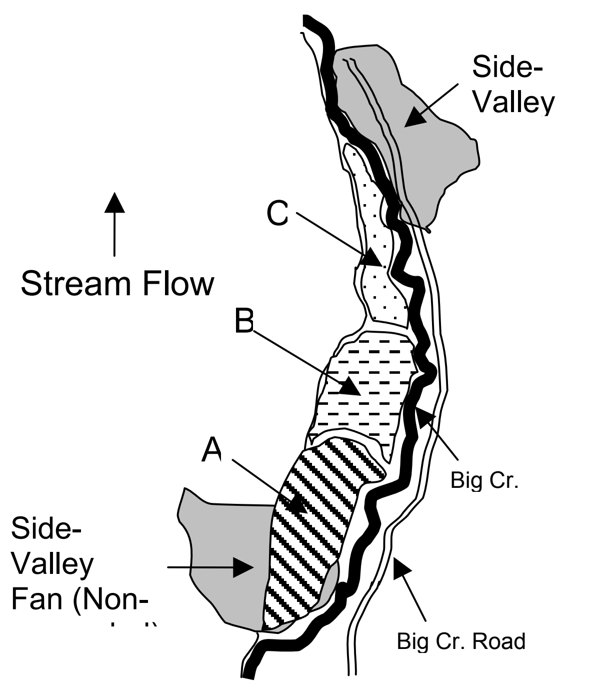

Figure 3. Big Creek hydrologic/hydrogeologic study site. After Jewett et al. (2003).

Vegetation Effects

The composition and abundance of riparian vegetation are influenced by geomorphic position and its influence on flood characteristics (frequency, magnitude, and duration) (Hughes 1997, Tabacchi et al. 1998), and water tables. For near stream vegetation types in central Nevada, median channel particle size (D_{50}), terrace height, width/depth ratio, channel slope, bank particle size (% < 2 mm), incised channel depth, number of terraces and bankfull depth all are related to vegetation type (Chambers et al. 2003). Terrace height, a surrogate for water table depth, is highly correlated with vegetation type. Similarly, in riparian meadow ecosystems, water table depth is often the major factor determining species occurrence (Castelli et al. 2001, Martin and Chambers 2001, Chambers et al. 2003).

Geomorphic factors that are related to vegetation type vary with respect to fan position. Riparian vegetation also exhibits distinct longitudinal patterns in watersheds with non-incised side-valley alluvial fans. Korfmacher (2001) characterized the riparian vegetation associated with side-valley fans in five drainages in central Nevada using high-resolution aerial imagery and a GIS. Figure 4 illustrates vegetation patterns by fan position and lateral distance from the stream. Above-fan locations exhibit a broader riparian zone with a significantly greater percentage of meadow vegetation types (wet and mesic) dominated by woody species, but with a significant presence of upland species. Characteristics of below-fan sites are variable but are similar to at-fan sites.

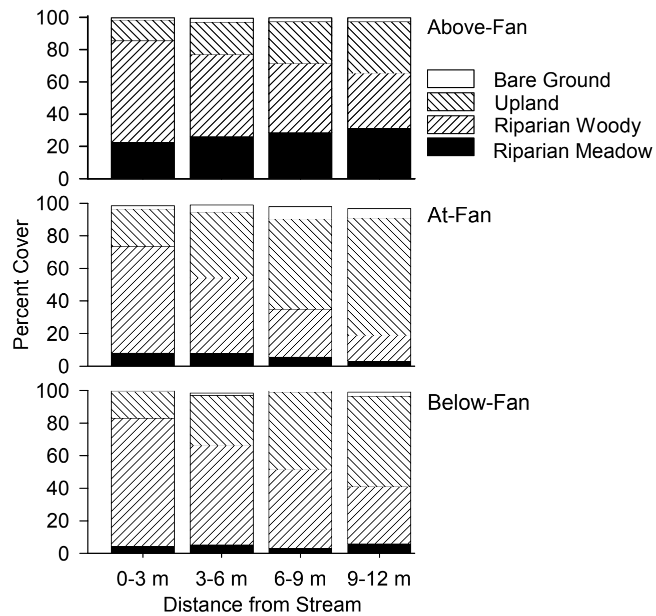

Figure 4. Mean percent aerial cover of riparian zone vegetation stratified by fan position and distance from stream at 53 locations in Big, Kingston, Washington, Cottonwood and San Juan Creeks, central Nevada (modified from Korfmacher 2001).

In watersheds dominated by alluvial fans, headcutting and incision can result in lowering the groundwater table associated with the stream and, consequently, loss of the shallow water tables that are necessary for meadow development and persistence. The fans and their associated riparian ecosystems can be described as metastable. The fans have increased watershed response times to natural and anthropogenic disturbances and preserved the meadow ecosystems, but multiple episodes of incision slowly result in progressive entrenchment as the streams work to smooth their longitudinal profiles.

Synthesis

In fan-dominated watersheds of central Nevada, side-valley alluvial fans have distinct effects on geomorphic processes, groundwater hydrology and riparian vegetation. Many of the riparian meadow complexes in the area are associated with side-valley alluvial fans. Because the stream systems in these upland watersheds are currently sediment-limited, they have an underlying tendency to incise that is being exacerbated by anthropogenic disturbances such as roads in the valley bottoms. This is resulting in progressive incision of the alluvial fans and the loss of valuable meadow ecosystems. Effective management of these watersheds requires an understanding of fan-related geomorphic processes, groundwater hydrology, and riparian vegetation dynamics.

To prevent the continued degradation of riparian meadow complexes associated with side-valley alluvial fans, proactive management/restoration will be required. Geomorphic analyses indicate that the fans tend to be coarser grained and more poorly sorted than upstream or downstream reaches (Davis 2000, Miller et al. 2001), and that the coarse grained nature of the fans has prevented or reduced the rates of incision through the fans (Miller et al. 2001). This suggests that techniques designed to directly increase the stability of the fans without blocking the movement of resident fish or aquatic organisms, such as grade control structures and armoring, may be highly effective. Current research efforts are focused on increasing our understanding the linkages between basin characteristics (morphometry, water yield), alluvial fan characteristics, groundwater systems, and riparian vegetation. This information in combination with knowledge of fan incision processes will be used to prioritize restoration/management activities.

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