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# Unintended consequences of rangeland conservation structures

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ABSTRACT

By the 1930's vast areas of the western US were severely degraded by overgrazing and erosion. In response, Congress authorized conservation work including the construction of erosion control and water storage, distribution, and conveyance structures. Thousands of structures such as check dams, water spreaders, and contour berms were built during the 1930s and 40s to control water and sediment in an attempt to restore degraded rangelands. However, across most of the western US, these soil and water conservation measures were implemented without the benefit of local hydrologic data or technical design guidance. Many of the established conservation practices had been developed for humid regions and were untested for use in semiarid areas that are characterized by highly variable rainfall and flash floods. As a result, many structures proved ineffective and were subsequently abandoned. Even in cases where structures were effective, many never received maintenance after their initial construction. Although structurally compromised, abandoned and unmaintained structures continue to alter surface runoff patterns and can greatly exacerbate erosion. Four sites in Arizona, USA were selected to characterize the multi-decadal impacts of conservation structures. Breaches have formed in 100% of contour berms (n = 67) while 96% of water spreader berms (n = 26) were compromised. Localized failures in these structures has created concentrated flow paths that reorganized routing of runoff and sediment thus transforming sheetflow regimes to concentrated flow regimes. This study emphasizes the unintended legacy impacts of soil and water conservation structures and highlights their role as a potential constraint on contemporary resource management.


## 1. Introduction

Structural control over surface runoff has a long history in drylands where rainfall, and thus runoff, is not evenly distributed on the landscape. Such structures range in sophistication from rudimentary berms that interrupt and spread surface runoff to complex systems for retaining and distributing water over long distances. Ancient systems for manipulating runoff to support cultivation have been found in the Middle East, Asia, Africa, and the Americas (Bruins et al., 1986), and some continue to capture runoff water to this day (Lowdermilk, 1960; Monger et al., 2015). These systems supported dryland agriculture by diverting and spreading surface runoff to increase the spatial extent and duration of plant-available water. Reorganizing runoff on the landscape also alters sediment distribution, thus many runoff control structures accomplish the dual purposes of increasing soil moisture and controlling erosion.

In North America, water spreading principles were more recently applied to address land degradation that by the 1930s affected large expanses of the southwestern US. In 1934, the passage of the Taylor Grazing Act (Public Law 73–482) brought 80 million acres of grazing land under federal management in part "to stop injury to the public grazing lands by preventing overgrazing and soil deterioration". In addition to regulating grazing on lands in the public domain, the Taylor Grazing Act initiated intensive on the ground efforts to manipulate surface runoff to mitigate and abate erosion problems.

In the years since the establishment of the USDA Natural Resource Conservation Service (formerly the Soil Conservation Service, established in 1935), a large body of knowledge has been developed to design structures and apply engineering principles to

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runoff and erosion problems. However, prior to the mid-1900s, there was a distinct lack of technical guidance for designing and applying conservation practices (Phelan & Basinger, 1993) particularly in semiarid landscapes that characterize much of the southwestern US. Rehabilitation of degraded US rangelands was further complicated by a general lack of technical information on precipitation variability and soil erodibility. High velocity floods and periods of droughts were, and are, common and posed particular challenges. As a result, much of the conservation work implemented during the 1930s was untested and could be considered experimental (Peterson, 1950).

Initial conservation work was done by hand and focused largely on watershed uplands, where a lack of vegetation and widespread soil erosion led to the concentration of surface flow in rills and gullies. Land treatment programs were initiated to reduce erosion, keep sediment at its source, and create conditions to support vegetation establishment. One common practice was the construction of low contour berms to intercept surface runoff and make efficient use of the limited amount of water that falls on the landscape. Contour berms were built using a variety of local materials including rocks, brush and wire, concrete, and earth. Another practice was water spreading. Larger earthen water spreader berms were constructed either singly or in series as a system for intercepting and distributing runoff. As a compliment to upland treatments, larger in-channel dams were constructed to induce aggradation within incised channels that had developed along valley floors. All of these structures were intended to retain sediment and water with the ultimate goal of re-vegetating degraded lands.

Early reports indicated that increased vegetation cover could be achieved using contour berms and spreader berms (Beutner, 1939; Semple & Allred, 1937), with local factors such as rainfall and soils playing a critical role in establishing vegetation that ultimately controls erosion (Miller et al., 1969). In their assessment of water spreading from 1935 to 1943 in northwestern New Mexico, Hubbel and Gardner (1950) documented the practice of distributing water as an effective means of increasing forage and preventing the movement of sediment to downstream water-storage reservoirs. However, they did note that the maintenance requirements for controlling water and sediment from large areas were disproportionately large. These assessments were paralleled by several studies under the Soil and Moisture Program of the US Department of the Interior to improve the design of effective and practical rangeland conservation methods (Burkham, 1966, pp. 1951–1960; Kennon & Peterson, 1960; Peterson & Branson, 1962). Reports from these and other studies (Peterson, 1950; Valentine, 1947) presented mixed reviews on the effectiveness of rangeland practices of the time. By 1960, the use of such structures to improve vegetation in the Southwestern US was questioned (Peterson & Branson, 1962), and contour berms and small earthen dams were largely dropped from rangeland conservation programs (Peterson & Hadley, 1960). A common theme is that the lack of basic data on precipitation, runoff, and soils often resulted in poor site selection, which contributed to project failures. These problems were exacerbated by poor construction practices, lack of maintenance, poor livestock management, and highly variable rainfall and runoff patterns.

Recently, rangeland water spreading has received renewed attention, and the effectiveness of water spreader berms for creating "islands" of enhanced soil moisture and primary productivity has been documented (Rango et al., 2006). In a 2009 review of water harvesting applications for rangelands, Rango & Havstad, 2009 present support for the use of such techniques in dryland conservation. Clearly, water spreading can produce localized, positive vegetative responses (Fig. 1).

Most of the literature on rangeland conservation structures focuses on manipulating soil moisture and vegetation responses,

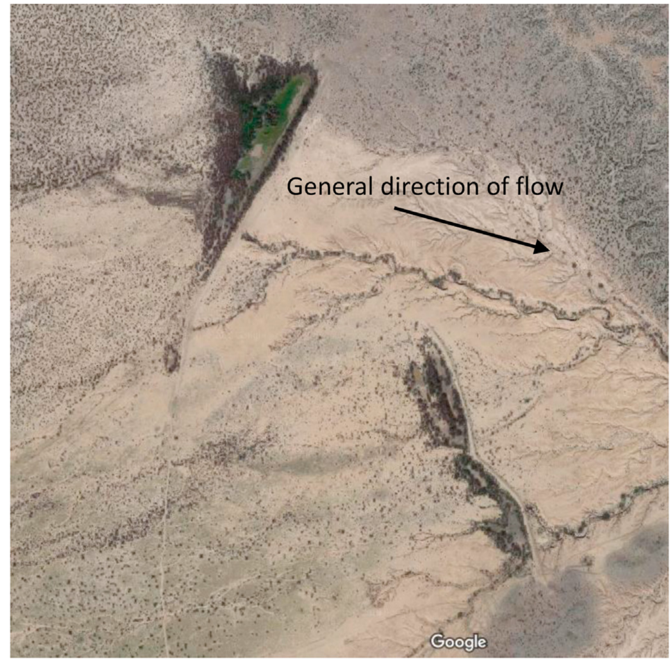


**Fig. 1.** Vegetation on upslope side of water spreader berms. Image sourced from Google Earth.

while the impacts of these structures on surface flow paths and geomorphic responses remain poorly documented. As a result, land managers lack basic information for making informed decisions on whether to abandon or maintain existing structures. A recent assessment of the geomorphic legacy of unmaintained water and erosion control structures in southern Arizona, US (Nichols et al., 2018) revealed that many historic structures have failed. The failed structures are exacerbating erosion by creating gully knickpoints that threaten large expanses of rangeland. Because of the ubiquity of conservation structures throughout western US rangelands and the vulnerability of arid and semi-arid landscapes to erosion, an assessment of their impacts on watershed physical processes can provide important information to land managers and restoration practitioners. This paper re-examines field sites that were evaluated by Peterson and Branson (1962) as part of a USGS project to review the effects of land treatments on erosion and vegetation in Arizona and New Mexico and adds an additional five and a half decades of perspective on the impacts of range improvement programs implemented during the years 1934 through 1942. In contrast to the focus of the 1962 appraisal of vegetation improvement, longevity of the structures, and quantities of sediment retained, our current objectives are to review the effects of land treatments on drainage and erosion patterns to understand the role of conservation structures in controlling landscape patterns and processes.

## 2. Materials and methods

### 2.1. Study sites

We evaluated three larger than 100 ha treatment areas (Fort Thomas, Indian Gardens, and Freeman Flat, Table 1) and one medium to large (greater than 5 m high) in-channel earthen dam within the Upper Gila River Watershed (Fig. 2). The Upper Gila Watershed includes approximately 39,350 km$^2$ of range, forest, and cropland in southeastern Arizona and western New Mexico US. Within the study area, precipitation is sparse and most is delivered

**Table 1**
Characteristics of study locations in Arizona, US.

| Site | Treated Area (ha) | Treatment Type | Geomorphic Setting | Soil Texture |
|---|---|---|---|---|
| Fort Thomas Wash | 105 | water spreader berms, contour berms | Alluvial fan terrace | sandy loam, fine sandy loam or loam in the upper part; can range to include finer or coarser textures in the lower part of the control section |
| Indian Gardens | 202 | contour berms | Alluvial fan | sandy clay loam, loam, sandy loam, loamy sand,10 to 25 percent clay |
| Freeman Flat | 242 | contour berms | Alluvial valley | loam, silt loam, very fine sandy loam |

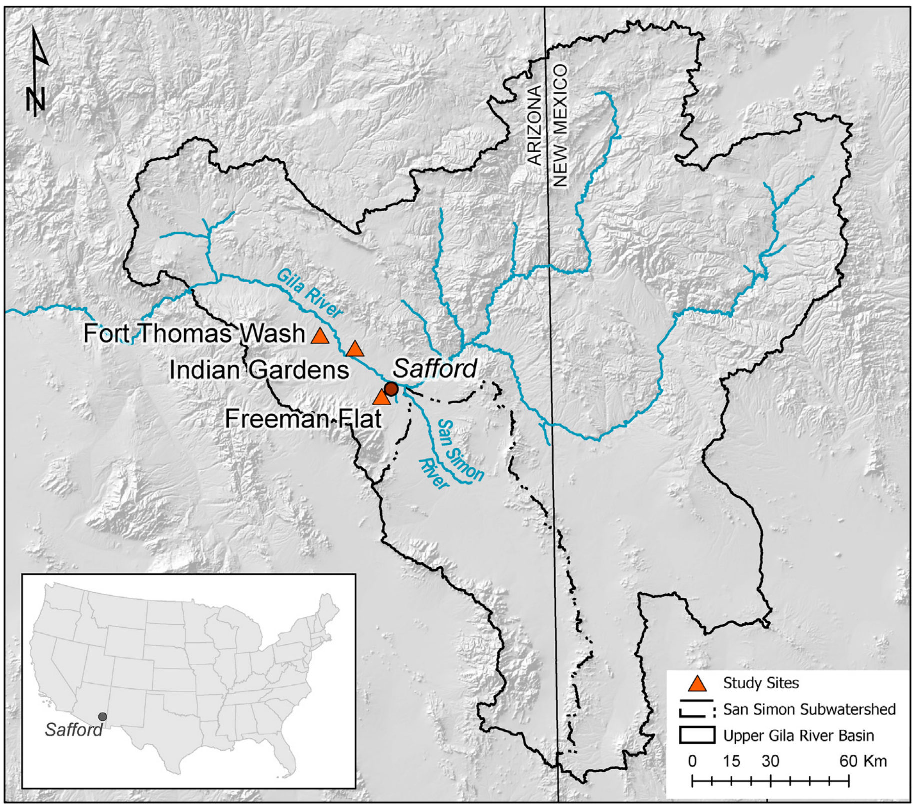


**Fig. 2.** General study site location map.

during high intensity summer convective storms (Sellers & Hill, 1974). Average annual precipitation ranges from 200 to 300 mm in valley bottoms to more than 1000 mm in higher elevation woodlands. Soils within the study sites range from silt loam to loamy sand, and vegetation is dominated by creosote bush (*Larrea tridentata*), mesquite (*Prosopis juliflora*), and annual grasses (Shreve & Wiggins, 1964).

Substantial land degradation in the late 1800s and early 1900s lead to widespread surface erosion, channel incision and gullying (Bull, 1997; Cooke & Reeves, 1976). In the 1930s and early 40s, Civilian Conservation Corps (CCC) personnel implemented range improvement projects to control erosion in the area. However, eight decades later the sediment production problem persists, and subwatersheds within the Gila Watershed are identified as major sediment sources in a recent Arizona Department of Environmental Quality draft Total Maximum Daily Load determination (USDA NRCS 2007).

## 2.2. Types of structures

Three types of structures were evaluated: contour berms, earthen water spreader berms, and an earthen dam (the H X dam). The contour berms were constructed by placing rocks on hillslopes (Fig. 3) along elevation contours to slow runoff velocities, retain sediment, and promote infiltration, thereby increasing soil moisture to support vegetation on upland areas. Earthen water spreader berms are larger structures constructed from local soil on both upland slopes and bottomlands. They operate by intercepting runoff and spreading it across the landscape and are sometimes constructed immediately upslope from gully heads to limit runoff at the headwall with the intention of minimizing headcut advance. Both contour berms and water spreader berms are often constructed in series to treat large areas. Large earthen dams are constructed in incised channels to control flood runoff and induce channel aggradation by trapping transported sediment. Eighteen in-channel dams were built in the Upper Gila Watershed between 1939 and 1981. During that period, the US Department of Interior – Bureau of Land Management (BLM) altered their strategy of focusing on handwork in watershed uplands to address the erosion problem and turned to constructing larger dams that would backfill deeply incised channels to create conditions favorable for re-establishing vegetation. The San Simon subwatershed (approximately 5830 km$^2$) is a dominant source of sediment to the Gila

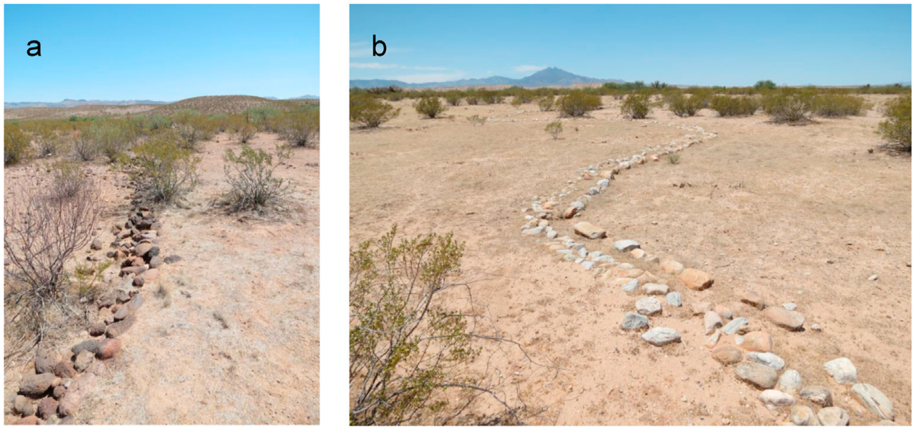


**Fig. 3.** Typical rock contour berms at a) Indian Gardens and b) Ft. Thomas Wash.

River (Olmsted, 1919) due to abundant highly erodible soils (USDA NRCS 2007) and thus has been a focus of larger scale structures for controlling sediment and contributing to watershed rehabilitation.

### 2.3. Structural integrity

We evaluated the structural condition of contour berms and earthen water spreaders based on aerial photographs, lidar data, and site visits. Structures and associated breaches (breaks through a structure) and flanks (scour around a structure) were identified by visually inspecting 2016 aerial imagery sourced from Google Earth. Structures were digitized and measured within Google Earth. A comprehensive analysis of the larger in-channel dams is beyond the scope of this study, but we include a summary of a specific breach at the H X Dam, which was constructed in 1956 across a tributary within the San Simon subwatershed, as an example of the potential impact of the failure of larger conservation structures (Fig. 5).

Hydrologic connectivity was assessed using flow accumulation grids created with the Hydrology Toolset in ArcGIS 10.4 (ESRI, Redlands CA) and Surfer (version 15, Golden Software, Golden CO.) to delineate flow paths. Topographic assessment at Freeman Flat was based on a 1m DEM created from aerial lidar data (approximately 3.3 points $m^{-2}$) collected in 2016 (https://nationalmap.gov/3DEP/). At Indian Gardens and Ft. Thomas Wash, where aerial lidar

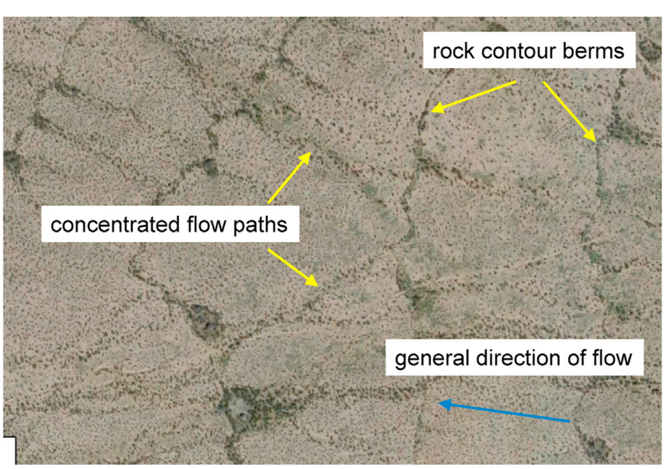


**Fig. 4.** Connected concentrated flow paths influenced by rock contour berms at Indian Gardens.

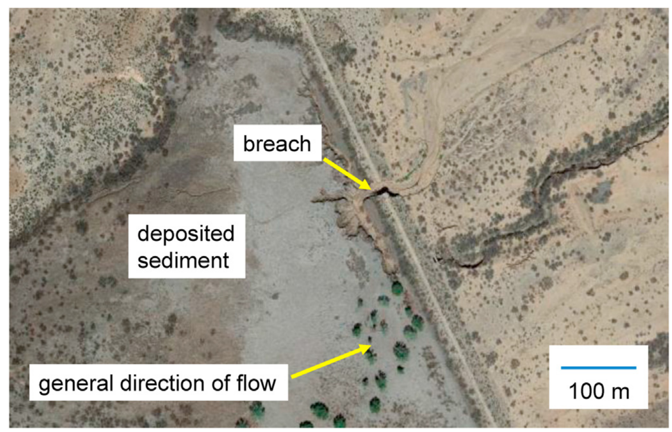


**Fig. 5.** Breached H X Dam and gully advance into accumulated sediment.

data were not available, aerial image interpretations were complimented by terrestrial lidar data collected in 2018. A Riegl VZ-400 terrestrial laser scanner (TLS) was used to collect data from multiple scan positions at each site using an inclination angle of 0.080°. The resultant average point spacing was 0.055m (330 points $m^{-2}$) at Indian Garden and 0.058m (297 points $m^{-2}$) at Fort Thomas field sites. Point density in the focal areas surrounding scanned structures was as high as 13,000 points $m^{-2}$. At each scan site, individual scans were aligned using 10 cm diameter reflective cylinder targets mounted on 200 cm poles. Individual scanned areas of approximately 0.05 ha were combined during post-processing using RiSCAN PRO 2.6 software (Riegl Laser Measurement Systems). Vegetation was removed using the Riegl Terrain Filter tool in combination with manual editing to produce bare earth point clouds from which digital terrain models were derived.

### 2.4. Channel capacity

We analyzed the bankfull channel capacity of the dominant incised channel that has evolved in response to structural failures at Freeman Flat. Cross-section geometry was extracted from 1m aerial lidar and discharge capacity was computed based on a standard application of Manning's equation, given

$n = 0.02$ to $0.04$. $Q = (1.00/n)\ A\ R^{2/3}\ S^{1/2}$

Where:

$Q$ = discharge ($m^3\ s^{-1}$)
$R$ = hydraulic radius = $A/P$ (m)
$A$ = cross sectional area ($m^2$)
$P$ = wetted perimeter (m)
$S$ = slope of channel (m/m)
$n$ = Manning's roughness coefficient

Channel discharge capacity was compared with probabilistic peak flows estimated using StreamStats (Paretti et al., 2014).

## 3. Results

### 3.1. Structural integrity

A total of 19 contour berms were identified at Indian Gardens and 27 at Ft. Thomas. There were 20 contour berms and 26 water spreader berms identified at the Freeman Flat site. Distinctive concentrated flow paths (Fig. 4) have breached all of the contour berms at each of the three sites, and the mean number of breaches per structure ranged from 4.2 to 7.8 (Table 2). Of the 26 water spreader berms at Freeman Flat, 16 (62%) have been breached or flanked and are no longer operating as designed, while seven (27%) have been both breached and flanked.

Conspicuous drainage patterns at each of the three sites show concentrated flow paths through breaches in the structures (Fig. 6). Displaced individual rocks at Ft. Thomas were identified in the 10 cm terrain model of the contour berm developed from the TLS scans. These displacements are associated with the occurrence of concentrated flow paths through the contour berm. Concentrated flow paths identified with the TLS derived terrain model were too subtle to be visible in aerial imagery. The TLS scans also reveal sediment accumulations on the upslope side of berms at Ft. Thomas in contrast to Indian Gardens where it appears that breaches and channelized flow through the berms have efficiently removed previously stored sediment. At Indian Gardens sediment accumulation was limited to localized areas in shallow deposition basins that were integrated into the berms during construction (Fig. 6).

The 8 m high 1200 m long H X Dam breached in 2014 and exemplifies the threat associated with the failure of larger structures. Although a 5.2M earthquake centered near Duncan, Arizona and the aftershocks that followed are suspected to be the direct cause of the breach, deferred maintenance may have played a role in the failure (W. Brandau, personal experience). Estimates by the BLM indicate that prior to the breach approximately 750,800 metric tons of sediment could have been stored behind the dam. The breach initiated gullying and the release of stored sediment to downstream river segments threatening to exceed the Total Maximum Daily Load for suspended sediment allowed to enter the Gila River (USDA NRCS 2007). The breach also defeated the flood control function of the dam. In this case, the threat of damage to downstream property, roads, and the water quality of the river justified repair of the dam. However, in the absence of eminent threats to safety, property, or environmental regulations in populated areas, many such dam breaches are not repaired, thus gullying and sediment release continue unchecked.

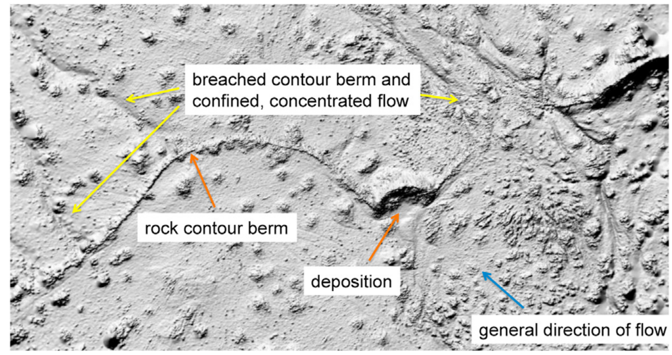


**Fig. 6.** Lidar hillshade image showing Indian Gardens rock contour berm with concentrated flow paths through the berm indicated.

### 3.2. Channel capacity

Topographic control imparted by the water spreader berms at Freeman Flat has resulted in conspicuous drainage pathways flanking the structures, coalescing in a dominant, single thread channel that conveys runoff through the valley (Fig. 7). Based on the cross-section geometry of the channel (average bottom width and depth of 1.2 m and 0.8 m respectively), and Manning's n values ranging from 0.02 to 0.04, the computed discharge capacity of the channel ranges from approximately 2.3 to 4.5 $m^3\ s^{-1}$. For reference, the estimated 2, 10, and 25-year return period flood flows in this subwatershed with mean annual precipitation equal to 260 mm and a contributing area of approximately 100 ha are 0.7, 3.4, and 5.4 $m^3\ s^{-1}$ respectively.

## 4. Discussion

All manmade structures have a limited lifespan. Most earth fill structures, such as small dams, dikes, and diversions will require maintenance or complete reconstruction every 20–25 years (French, 1957). These expected lifespans are probably optimistic when applied to structures in semiarid regions. For example, soon after conservation work began in the Upper Gila Watershed in the 1934, project evaluations indicated that more than half of the structures were breached within a few years after construction (Peterson & Branson, 1962), and they did not prove to be an effective tool for restoring degraded lands. We show that structural failures are widespread in this region eight decades after construction, and that the compromised structures strongly control the hydrologic and geomorphic evolution of these landscapes in ways that are counter to their original intention.

### 4.1. Hydrologic and geomorphic process impacts

Once built, the fate of water spreader berms and contour berms is to be either maintained or abandoned and thus subject to failure. Whether maintained or not, these structures are essentially permanent features over management (decadal) timescales. Even if they have failed and are not operating as intended, structures are

**Table 2**
Characteristics of contour berms at three sites.

| Site | Number of Structures | average length (m) | breaches per structure (mean, min-max) |
|---|---|---|---|
| Fort Thomas Wash | 27 | 200 | 7.1 (1–22) |
| Indian Gardens | 19 | 380 | 7.8 (1–16) |
| Freeman Flat | 20 | 200 | 4.2 (1–10) |

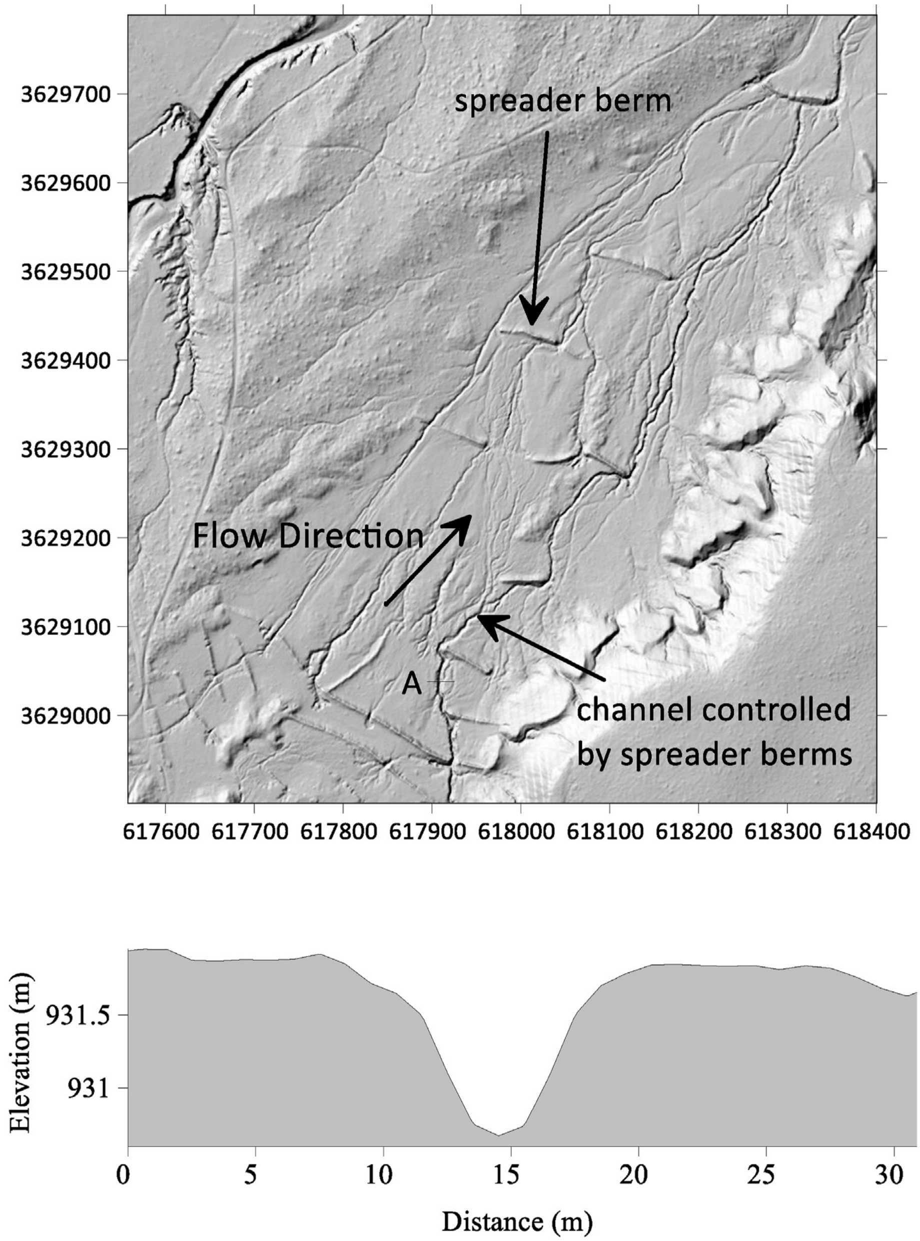


**Fig. 7.** Lidar hillshade image showing incised channel aligned with water spreader berm ends at Freeman Flat and typical channel cross section labeled A in top panel.

rarely removed. We have shown that their persistence on the landscape can create the unintended consequences of altering surface flow paths, concentrating runoff, increasing channelization, exacerbating erosion and remobilizing stored sediment.

At Indian Gardens and Ft. Thomas Wash, distributary flows that typify runoff on alluvial fans (Bull, 1977) transported and deposited sediment that accumulated to form surfaces that were later eroded when vegetative cover was reduced. Historically, at Freeman Flat deposited sediment filled the alluvial valley bottom which deteriorated as gullies formed in response to overgrazing. Conservation structures were built to reduce flooding and control erosion. Both contour berms and water spreaders interrupt overland flow, slowing runoff velocities and allowing time for soil moisture to be replenished through infiltration. However, the act of slowing and spreading water also deposits sediment carried in suspension. With sufficient accumulation, deposited sediment creates topographic high regions causing runoff to seek new, more efficient pathways downslope. Runoff that concentrates in response to these topographic highs creates new flow paths through or around the end of a structure. Once constructed, soil and water conservation structures impart a persistent artificial control on topography that alters hydrologic connectivity.

Contour berms are thought to be self-maintaining because by design they reduce slope lengths and gradients, and thus flow velocities, allowing runoff to pass over and through in a non-erosive manner. When working as designed, low volume sheet flows can spread laterally and seep through spaces between rocks, and larger flows can cascade non-erosively over the berms. If rocks are displaced by animals or during heavy runoff, incisions can form in the berm crest. A feedback loop is then initiated where these preferential flow paths gradually enlarge through downcutting, lateral expansion, and headcut migration as they capture more runoff (Schumm, 1977). Once these channels develop into networks large enough to modify landscape drainage patterns, runoff is transformed from a sheetflow regime to a concentrated flow regime. When operating as designed, contour berms create low terraces as material transported from upslope accumulates behind each berm. At Ft. Thomas Wash, low terraces can be clearly identified and many of these contour berms continue to act as sediment sinks. However, concentrated flow paths through the breached contour berm indicate that the berm is not operating as intended and has failed. A consequence of berm failure is that sediment stored on the upslope side can be mobilized thus becoming a sediment source to downslope areas. In contrast to Ft. Thomas Wash, the degree of concentrated flow and breaching at Indian Gardens is high enough that sediment accumulation is now limited to short sections of remnant berms. Although the berms at Indian Gardens are not effectively storing sediment, they are controlling downslope delivery.

Like contour berms, water spreader berms are also designed to route excess runoff as shallow, non-erosive spillovers. However, as seen at Freeman Flat, sediment accumulation behind water spreader berms eventually results in lateral channel migration that ultimately flanks the structures, thereby modifying channel network development throughout the valley. Currently, small to moderate runoff events (less than 25 year return period) that formerly would have spread across the valley floor are confined to actively incising channels. During subsequent runoff events these channels are expected to expand through channel bed and lateral bank erosion (Schumm, 1977; Webb & Hereford, 2010). As the channel incises and conveyance capacity increases, it will confine increasingly larger flows and further prevent runoff from spreading laterally over the valley floor.

Erosional features associated with unmaintained soil and water conservation structures can cause lasting changes to hydrologic connectivity (Nichols et al., 2018). Longitudinal connectivity is increased as runoff from upper valley segments is efficiently routed down-valley by actively eroding single threaded channels, while lateral connectivity is dramatically reduced because runoff that formerly spread across the valley floor is now confined to concentrated flow paths. Changes in connectivity, described by the length and number of pathways connected to move water and sediment, are a key indicator of desertification (Okin et al., 2009). On floodplains and valley floors, structurally induced lack of sheetflow is a disturbance that has the potential to reduce vegetative cover (Schlesinger & Jones, 1984) and alter vegetation composition (Steinfeld & Kingsford, 2013).

### *4.2. Implications for land management*

In contrast to more diffuse drivers of connectivity changes, such as climate, this study identifies a direct and ubiquitous cause of altered hydrologic connectivity that is structural, man-made, and in some cases potentially reversible. Understanding the role of failed conservation structures as a dominant control on hydrologic and geomorphic processes, and thus as a control on contemporary evolution of these landscapes, is critical for understanding the limitations of both management tools and implementation strategies. Given the geographic scope of managed rangelands, and the extent of efforts to control water and sediment during the past century, large areas are of the southwestern US are likely affected by failed or abandoned conservation structures. For example, in the Upper Gila Watershed alone more than 4000 structures, not including small berms and rock dams, have been identified and inventoried (Banister et al., 2014; Brandau et al., 2013). More than 1000 structures have been identified in the Altar Valley in southern Arizona (Nichols et al., 2018). In cases where the unintended hydrologic and sedimentary impacts of structures is relatively recent, there may be opportunities for mitigation.

Structurally induced shifts from sheetflow to concentrated flow can constrain vegetation management. Grasses adapted to periodic inundation may be replaced by shrubs, annual herbs, and bare soil in areas where concentrated flow has reduced the spatial extent of runoff infiltration and soil moisture recharge. In less extreme cases, plant vigor and forage production would likely decline. It is important to note that in terms of forage production and vegetative cover, all four of our study sites are located in ecologically marginal landscapes where it would be difficult to justify the cost of maintaining structures based on vegetation criteria alone.

Information on the existence, condition, and impacts of legacy rangeland conservation structures should be explicitly integrated into land management decisions. However, because of complex land ownership patterns and governmental management responsibilities, no single database of structures exists, and current inventories likely underestimate the true number of structures. Although high resolution topographic data sufficient to inventory conservations structures are becoming more common, readily accessible 10 and 30 m digital elevation models are often not detailed enough to capture most structures or their impacts. Nevertheless, simple inventories and assessments of legacy structures could be incorporated into ongoing management activities. For example, brush removal projects should specifically include a survey of existing water and erosion control structures, their condition, and any associated erosion damage or altered runoff patterns as these factors may ultimately drive the success or failure of restoration attempts.

Managing legacy structures is inherently multifaceted and is fundamentally constrained by budgets. Further, maintenance is often complicated by policies within federal and state agencies that limit support for such work within each agency to structures that each specific agency designed and built. Although the heyday of water spreader construction in the southwestern US was from about 1930 through the 1970s, and fewer are built now, there are ongoing maintenance needs. Periodic assessments can identify relatively small structural problems that can be mitigated. However, if maintenance is deferred, small breaches can become costly problems. The recent repair to the breached HX dam reached into the hundreds of thousands of dollars.

An additional constraint on maintenance is imparted by time. In the US, structures that are at least 50 years old and have some level of historic significance qualify for a historic designation under the National Historic Preservation Act of 1966. Thus, many of the conservation structures built by the CCC eight decades ago qualify for historic designation, which further complicates maintenance. In many cases, the now historic structures are associated with prehistoric Native American cultural resources, and preventing maintenance is justified to preserve cultural values. However, as the landscapes continue to erode, both conservation structures and cultural resources are threatened. It is not without irony that the Act to preserve historic structures has the potential to unravel landscapes vulnerable to erosion and gullying exacerbated by unmaintained structures.

## 5. Conclusion

We highlight the very serious and ongoing problems of erosion and altered hydrologic connectivity induced by unmaintained conservation structures and the constraints these conditions place on future land management. Soil and water conservation structures are common features of the western US landscape, and many historic structures have been abandoned or not maintained. Current land managers are faced with the challenge of deciding what to do with them in the face of limited dollars. Maintenance can be costly, but abandonment of a structure often includes societal costs in the form of degraded lands, altered vegetation, and loss of cultural resources that are caused by altered runoff patterns and enhanced erosion. Because of the large number of structures and spatial extent of the landscapes they affect, new evaluation tools are needed to help prioritize maintenance and management. These tools should build on current knowledge of watershed physical and vegetation characteristics, as well as land use history, while accounting for hydrologic and geomorphic impacts of existing conservation structures.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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