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The landscape impact of unmaintained rangeland water control structures in southern Arizona, USA

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ABSTRACT

Water development has transformed the topography of rangelands. This study investigated the associated hydrologic and geomorphic impacts of structures such as earthen berms, stock tanks, and road drainages in a semiarid rangeland in the Altar Valley in the southwestern USA where land use has been dominated by livestock production since the late 1800 s. The condition of remnant and operational runoff and erosion control structures was inventoried, mapped, and assessed using aerial imagery and Light Detection and Ranging (LiDAR) data. A total of 377 stock tanks are distributed throughout the valley where they are a control on runoff and sediment transfer. Almost half of 59 identified lateral channel berms (41%) have been breached and 17% have experienced lateral scour; 15% of 667 shorter water spreader berms have been breached and 29% have experienced lateral scour. Although landscape evolution in the valley is ultimately driven by regional geomorphic instability caused by channel incision and land cover changes, manmade structures are currently an important control on hydrologic and geomorphic processes, especially where not operating as intended. Due to the spatial extent of rangelands managed for livestock grazing and the large number of manmade structures distributed within, the results of this study are important for informing the role of humans in altering even seemingly sparsely impacted lands.

1. Introduction

Across the western US the dominant agricultural land use is livestock production (Starrs, 1998; Sheridan, 2012; Sheridan et al., 2015). Within the state of Arizona, approximately 98% of agricultural lands are grazing lands that cover approximately 73% of the total land area (Kerna et al., 2014). Although livestock were introduced in the 1500 s in the southwestern US (Hamilton, 1884), the expansion of ranching operations, on both private and public land, was limited by access to water. Water development was rapid once well drilling and pumping equipment became available in the late 1800 s (Wood et al., 2005) after which livestock numbers increased substantially in response to both transcontinental railroad construction and water access throughout the western US (Wagoner, 1952).

In the early 1900′s, the US Agricultural Extension Service implemented range improvement programs in semiarid regions, in part to address water supply and distribution. Improvements included construction of dams, stock tanks, wells, and developing springs (University of Arizona Agricultural Extension Service, 1932). These efforts were followed by large-scale water improvement projects in the 1930s with the technical guidance of the newly formed US Soil Conservation Service. Many projects were implemented in cost-share arrangements with ranchers who sought to dig or drill wells and construct earthen stock tanks for water supply in locations that altered water distribution to align the distribution of cattle and forage (Bailey et al., 1996). Surface-water runoff was also intercepted and diverted by earthen spreader berms and long dikes (Helms, 1992) to enhance soil moisture to support vegetation. These structures also altered sediment dynamics and were often constructed to mitigate erosion problems.

Commonly, livestock grazing impacts are managed based on the well-established principles of manipulating stocking rates (number of animals per unit area per unit time) and animal distribution across the landscape, which is effectively accomplished with fencing and distributed water supplies. Much of the literature interpreting impacts of the use of rangelands focuses on grazers and their widely varying ecological impacts (Briske et al., 2008; Briske et al., 2011). Managed rangelands are also impacted by altered fire regimes, fragmentation due to roads and fences, and changes in water flows and quality (Freilich et al.,

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2003). Far less attention has been paid to the landscape impacts of infrastructure needed to manage livestock, in particular water infrastructure. The local and cumulative effects of structures built on rangelands to alter surface water runoff are largely undocumented. No single database exists to characterize the extent of structural control over runoff within the western US, and from the point of view of the casual observer, the presence of manmade structures critical to livestock production and built to manipulate and control water remains concealed in the vastness of open spaces. A fundamental first step in understanding the impacts of manmade structures is an inventory and assessment, which is increasingly possible with high-resolution topographic data and satellite imagery such as that available for the Altar Valley, a semiarid rangeland watershed in southern Arizona, USA (Fig. 1).

In 1862, Major David Ferguson, first cavalry, California volunteers traveled from Tucson, Arizona, US to Sonora, Mexico via Arivaca and the Altar Valley. In addition to describing fine nutritious grass and open country, he noted, “There is a cienega of considerable extent that can be easily drained, and several hundred acres of valuable arable land reclaimed”. His description of “grass as far as the eye can reach; excellent ranges for sheep and cattle” extended to the current area of Sasabe, AZ. Critically, in a region noted for its aridity, Ferguson also documented watering locations and the presence of charcos (natural waterholes) (Ferguson, 1863, pg 15). Certainly, the locations of natural spring and seeps were known to native inhabitants (Bryan 1925), but at the time, local water supply needs were limited to humans and animals passing through as the valley was unoccupied by people. The anticipated ranges for sheep and cattle would require intensive water development.

Twenty years later, Sidney DeLong led a survey party through the Altar Valley, Arizona for the Tucson and Gulf of California Rail Road. The area between the Sierrita and Coyote Mountains was described as having “excellent soil, but it lacks water and means of irrigation”. A reporter traveling with the survey party noted “The range is excellent

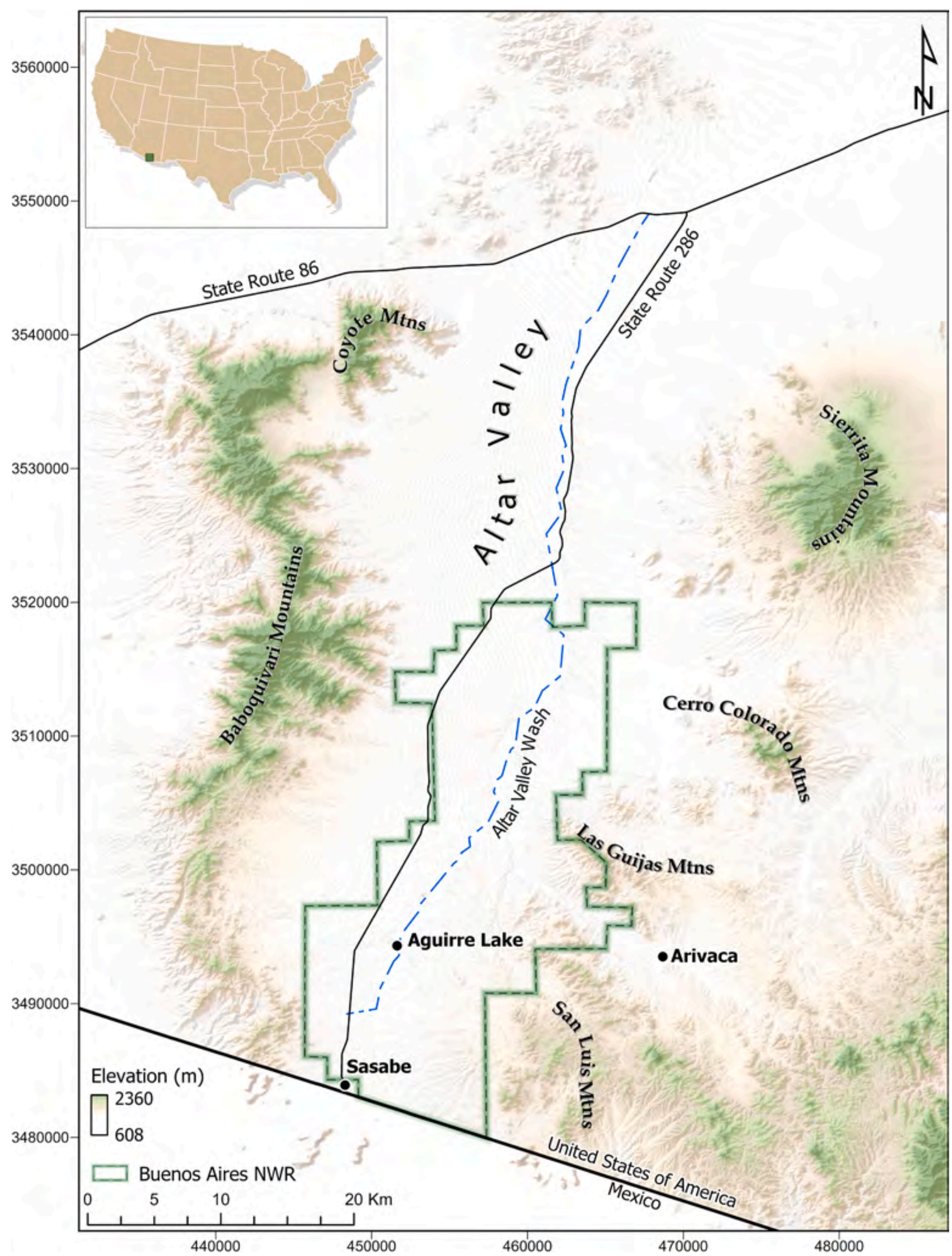

Fig. 1. Study area location map.

and doubtless before many years this section will be thickly dotted with extensive ranches and inhabited by a prosperous payple (sic)" (Arizona Weekly Citizen, May 7, 1882). All that was needed was water.

When the original US General Land Office plat maps covering the headwaters townships and ranges of the Altar Valley were filed, water development by Anglo-Americans had begun. A map filed in 1888 contains a single charco (a natural depression with a built up water holding berm) located at the site of Aguirre Lake (located on the present day US Fish and Wildlife Service Buenos Aires Wildlife Refuge (BANWR, est. 1985) and makes note of a higher elevation windmill and springs. Runoff that collected in the manmade lake during the summer monsoon season was critical for irrigating land and supported the former Buenos Aires Ranch. During the next 130 years, more than 1500 manmade structures would be built to alter surface water runoff throughout the Altar Valley (Nichols et al., 2018; current manuscript), largely in support of livestock production.

This paper presents an inventory, assessment, and interpretation of surface-water runoff and erosion-control structures in the Altar Valley, which has been grazed by cattle for at least a century. The overall goal of this study is to provide fundamental information that is needed to increase the accuracy of future hydrologic simulation modeling. A spatially explicit database of manmade water and sediment control structures associated with ranching is described toward understanding their impacts as both short-lived and persistent controls on hydrologic and geomorphic processes in the valley. This study is important as it exemplifies and quantifies the spatial extent of structural control over water and sediment and identifies human-altered runoff patterns and geomorphic responses associated with rangeland-management infrastructure. This knowledge is a critical first step toward understanding the role and persistence of manmade structures as a control on hydrologic connectivity and landscape evolution. The US federal government manages grazing on approximately 64,000 sq. km (Merrill and Leatherby, 2018). Given the geographic extent of livestock grazing in the western US, the cumulative impacts of water development in support of grazing likely are extensive.

2. Methods

2.1. Study site

The inventory and assessment was performed in the 247,000 ha semi-arid Altar Valley (Fig. 1) located in southern Arizona, USA. The 72 km long basin is located in the western North American Basin and Range Physiographic Province. This study focuses on the area south of highway 86, and north of the US/Mexico International Boundary. The results extend and include a recent inventory and assessment of the geomorphic legacy of rangeland water and erosion control structures on the BANWR (Nichols et al., 2018), which is located in the southern headwaters of the valley. The BANWR occupies approximately 20% of the watershed and has not been grazed by cattle since 1985. The remaining 80% of the valley supports nineteen agricultural operations, primarily ranches, ranging from 4,000 to 28,000 ha. These ranches are made up of a mosaic of private, federal, state, and county owned lands.

The valley drains northward from the US-Mexico border; however, as previously noted, natural surface water is sparse. Within the Altar Valley, there is no naturally occurring perennial surface water. All channels are ephemeral and flow primarily in response to intense and infrequent summer convective thunderstorms that generate flash floods. More than half of the 415 mm of annual rainfall occurs from July-September during the North American Monsoon (Adams and Comrie, 1997). The valley is surrounded by the Baboquivari and Coyote Mountains to the west and the Cerro Colorado, Sierrita, Las Guijas and San Luis Mountains to the east. Altar Valley encompasses approximately 247,000 ha of desert grass and shrub land within which elevations range from approximately 750–2350 m.

2.2. Types of structures

Surface runoff in the valley is controlled with stock tanks, long berms, spurs, short berms, constructed channels, and concrete dams. In addition, features such turn outs and lateral berms are associated with unpaved ranch roads. A recently (2014) constructed natural gas pipeline also alters topography and drainage. Historically, surface runoff in the southern, headwaters end of the valley was also managed with manually operated flow control gates that are now non-functional but remain unattended on the landscape (Nichols et al., 2018).

Stock tanks temporarily store surface runoff behind earthen dams constructed by excavating local dirt to create a small basin. Tanks are constructed either in or lateral to well-defined channels as well as on uplands where they are sometimes coupled with water harvesting berms that direct intercepted runoff into the excavated basin. In several places, channels were constructed by bulldozing pathways to divert runoff into stock tanks, sometimes accomplishing inter-basin transfers (Fig. 2). In higher watershed elevations, concrete dams were constructed across drainages to capture in-channel runoff and sediment. Earthen berms are found throughout the valley and accomplish both runoff and erosion control. Incised, steep walled channels are paralleled by long berms, sometimes for thousands of meters, to protect against further bank erosion (Fig. 3).

In many cases, short earthen spurs have been constructed perpendicular to long earthen berms to intercept and slow the velocity of runoff that travels along the upslope berm face. Water spreaders are shorter linear earthen berms (Figs. 4 and 5) constructed of local soil to intercept surface runoff water and temporarily store it thus increasing the time for soil infiltration to replenish soil moisture that can enhance vegetation (Rango and Havstad, 2011).

2.3. Structure inventory and assessment

Imagery from 2016 within Google Earth and digital elevation models (DEMs) were visually interrogated to interpret current conditions. Aerial LiDAR data (2011 and July 9–14, 2016) sourced from Pima County Regional Flood Control district were used to create 1 m DEMs that facilitated identifying structures that were not evident in the 2D imagery. Structures were identified and digitized as point or line features using ArcMap (ArcGIS Desktop [version 10.4], ESRI, Redlands CA). Long berms and water spreader berms were digitized as polylines by visually inspecting aerial imagery. Breaches (a break through a structure) and flankings (scour around a structure), and associated flow paths through and/or around structures, were also visually identified in aerial imagery and in hillshade 3D representations of the landscape surface developed from the DEMs.

Long earthen berms were further classified according to purpose. We classified lateral channel berms that are intended to reduce lateral channel bank erosion, agricultural berms that prevent field flooding, gully erosion control berms constructed upstream of gully heads to prevent runoff from reaching the advancing headwalls, road protection berms, and berms constructed to direct runoff water into stock tanks. In cases where the purpose of the berm was not evident, they were classified as "other". These classifications are based on purpose in managing soil and water on rangelands that are used for ranching and do not imply definition related to engineered structures.

3. Results

3.1. Stock tanks

The spatial distribution of 377 stock tanks is shown in Fig. 6. Although it was not possible to accurately determine the structural condition of stock tanks based on remotely sensed data, they are ubiquitous and alter runoff throughout the valley. A comprehensive evaluation of the structural condition of stock tanks will require field visits to

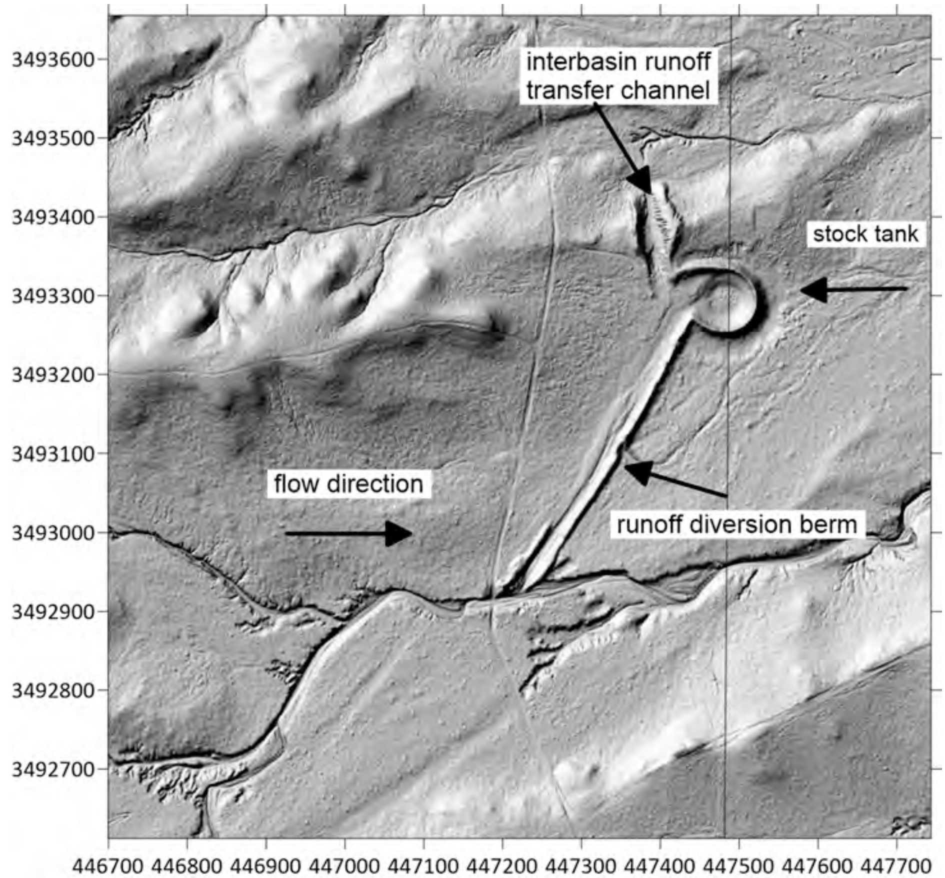

Fig. 2. Example of a stock tank coupled with a diversion berm to direct runoff from the channel into the basin. Also shown is a manmade channel constructed through hillside to capture runoff from the adjacent watershed.

verify the state of sediment accumulation and diminished storage capacity, as well as both dam and spillway integrity.

3.2. Earthen berms

Earthen berms are the most numerous type of rangeland water control structure in the valley (Table 1, Fig. 7). 851 earthen berms were identified and classified. Of these, 184 are long earthen berms, many of which parallel the Altar Wash and 667 are shorter earthen water spreader berms. For a given structure, the presence of a single breach was sufficient to be classified, and many of the longer berms are breached in more than one location. Overall, approximately half of the earthen berms have been breached, flanked, or both.

Within the Altar Valley, earthen berms are distributed with respect to landforms and purpose, and local spatial arrangement varies among individual ranches. The dominant purposes of earthen berms are 1) mitigating lateral channel bank erosion, 2) floodplain water spreading, and 3) upland water spreading. The Altar Wash is protected from lateral channel bank erosion along 41.3% of its length by long earthen berms (Fig. 7), however, only nine of the 59 channel bank protection berms did not show evidence of a breach or flank. Many of the berms that are breached or flanked are posing erosion risk to adjacent floodplains (Fig. 4). The dominant purposes of the long berms are channel protection and water diversion to direct runoff into stock tanks (Table 2). The channel protection berms experienced a high (85%) failure rate in contrast to the stock tank diversion berms that experienced a much lower (30%) but still high rate of failure. Road protection berms experienced the lowest failure rate, likely a reflection of maintenance. Agricultural berms protect high value croplands which is reflected the fact that 68% are intact. Shorter berms are concentrated on floodplain and the west side of the valley on alluvial fan surfaces (Fig. 7). Only 347 of 667 (52%) shorter water spreader berms remain intact, while 15% have been breached and 29% have been flanked.

3.3. Other structures

Other manmade structures in the valley include check dams, concrete runoff control structures, rock gabions, and short earthen spurs (Table 1). The count of check dams is likely low. It is known that over time, hundreds have been constructed, but records are generally unavailable. These structures are small enough that they are often not evident even in high-resolution DEMs, and thus field verification is needed to locate and assess them. Concrete runoff control gates are principally located on the BANWR and are legacy structures from prior ranching endeavors (Nichols et al., 2018). Many of these sit flush on the landscape, however in some cases scour around the concrete is a direct cause of gullying.

In 2014, a natural gas pipeline was constructed longitudinally through the valley. 427 topographic alterations to minimize erosion and sedimentation on lands affected by construction were identified. In addition, 161 relatively small features associated with roads were identified, but not evaluated further. Most of the road features either prevent runoff from reaching a road or facilitate road drainage. However, at least two of the road features were intentionally constructed to provide conservation benefits. Three quarters of the rock-filled gabions structures, which were constructed more recently in the 1990 s, have failed and have experienced lateral scour. They remain in situ and are a control on drainage pattern as evidenced by lateral scour paths. In addition, field visits revealed ancillary structures such as corrugated metal drainpipes integrated into berms to limit upslope ponding. These

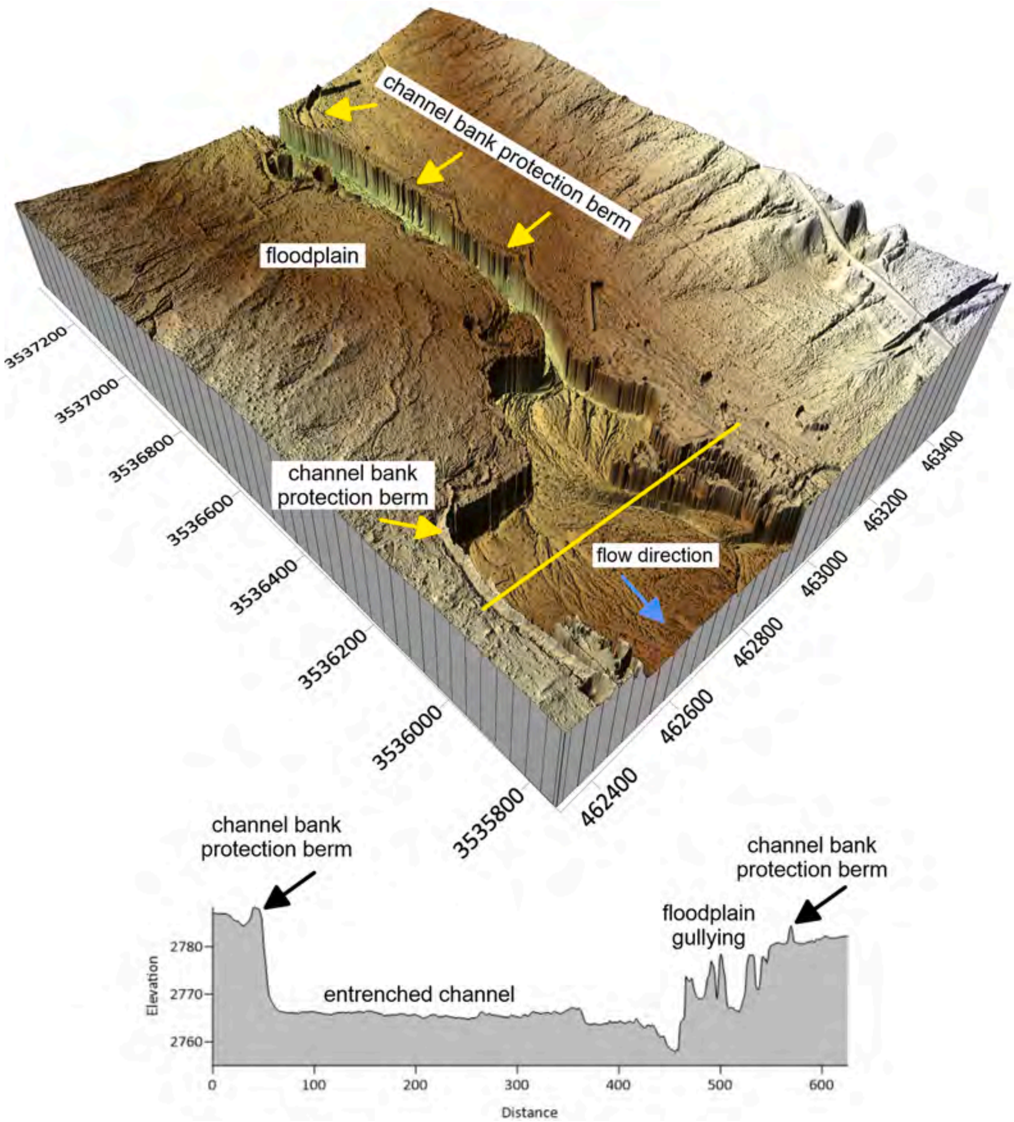

Fig. 3. Example channel reach within the entrenched Altar Wash. This reach is protected on both sides with lateral earthen berms to prevent runoff from reaching the top of the vertical channel banks. The plotted cross section is located with the yellow line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

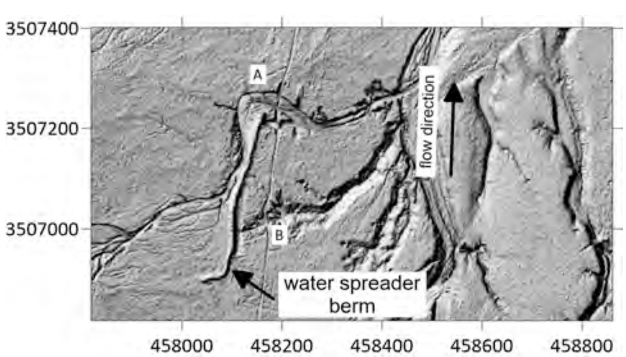

Fig. 4. Example earthen water spreader berm located on a floodplain. Concentrated flow has routed around the berm (A) creating an incising channel. This berm also serves to halt the advance of a gully (B).

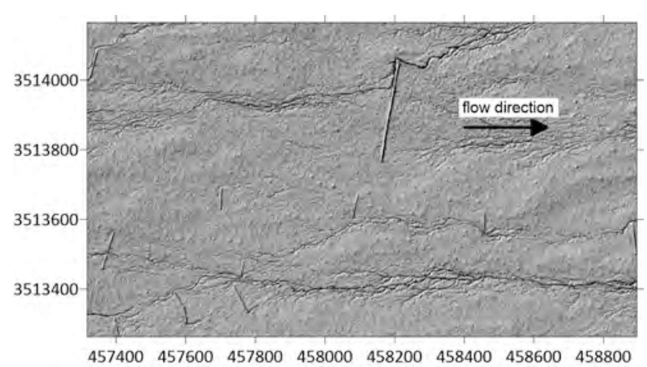

Fig. 5. Example earthen water spreader berms located on an upland alluvial fan. Concentrated flow paths have developed to route runoff around the berms thus defeating their water spreading purpose. The berms are a control on drainage pathway position, which is further reinforced as concentrated flow causes further channel incision.

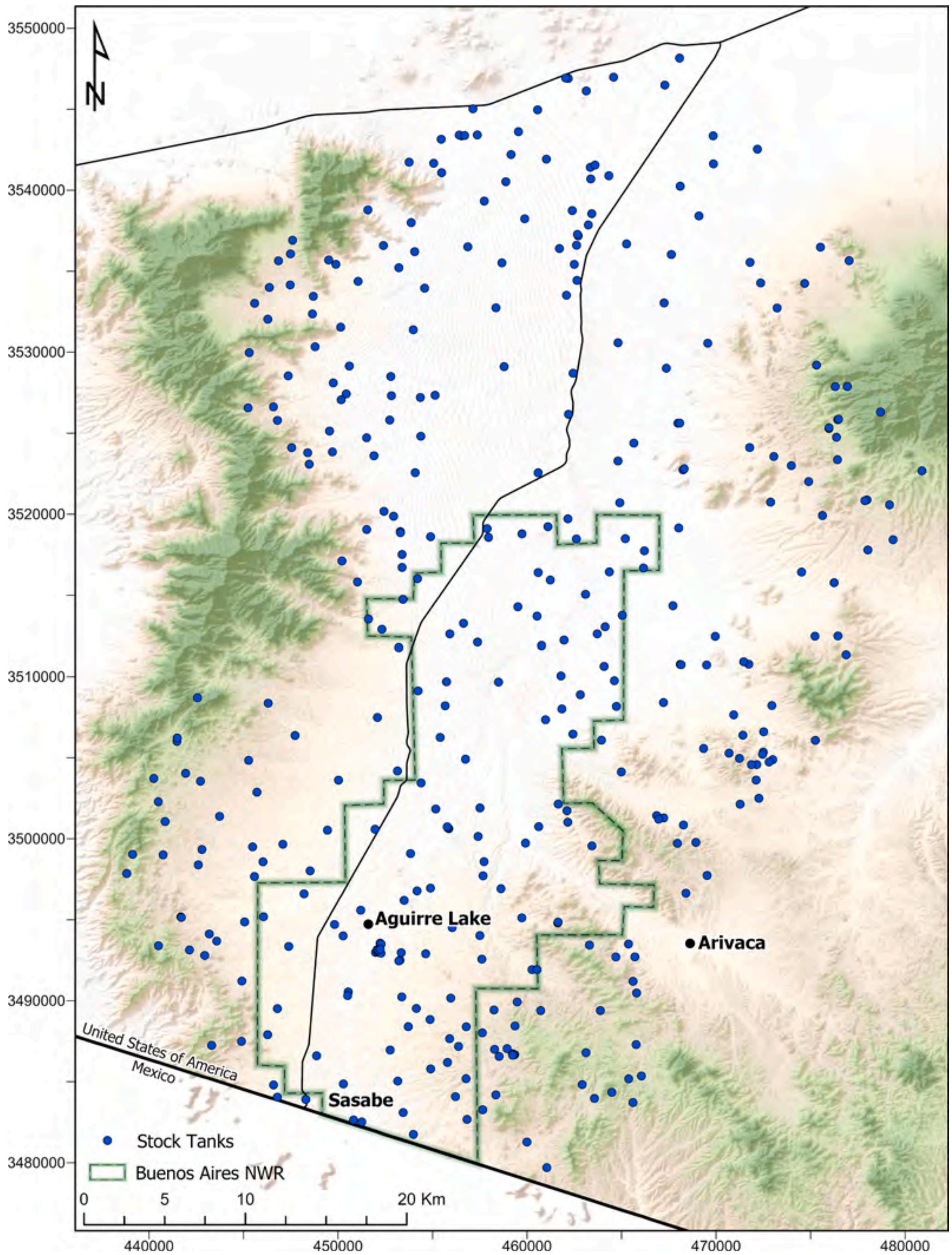

Fig. 6. Distribution of stock tanks in the Altar Valley.

Table 1
Summary of water and erosion control structure condition in the Altar Valley, Arizona, USA.

			Count							
Structure Type	Count	Length (m) Median (Min-Max)	Intact	Breached		Flanked		Breached and Flanked	
Long Berm	184	385 (54–5246)	90	53	29%	17	9%	23	13%
Water Spreader Berm	667	68 (13–521)	347	102	15%	196	29%	22	3%
Check Dam	37	30 (13–58)	35	1	3%	1	3%	0	0%
Concrete Structure	29	15 (5–59)	25	2	7%	2	7%	0	0%
Rock Gabion	4	32 (16–40)	1	0	0%	2	50%	1	25%
Spur	65	35 (12–143)	49	10	15%	6	9%	0	0%

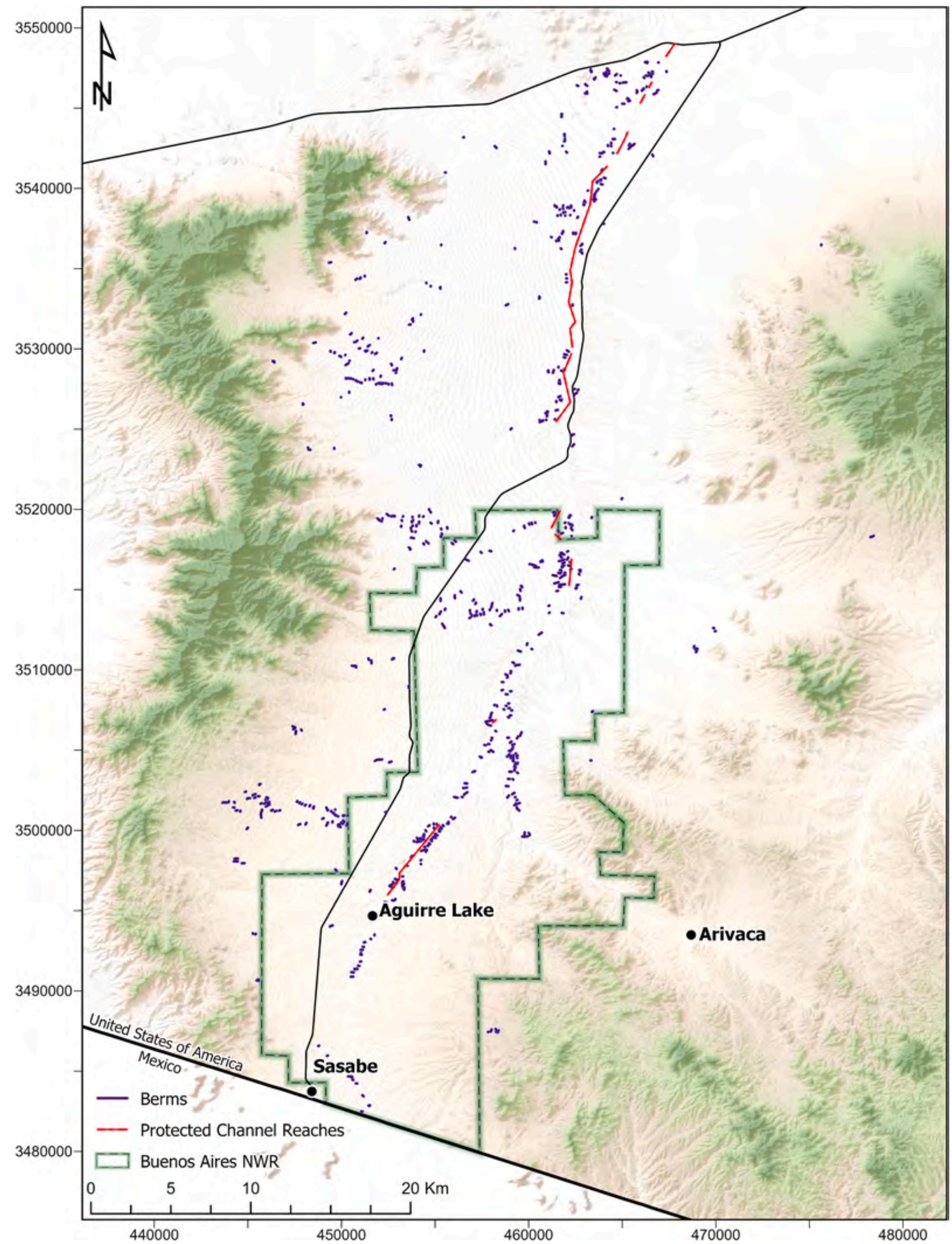

Fig. 7. Distribution of channel bank protection berms and shorter water spreader berms.

Table 2
The condition of long earthen berms in the Altar Valley, Arizona, USA.

			Count						
Long Berm Purpose	Count	Length (m) Median (Min-Max)	Intact	Breached		Flanked		Breached and Flanked	
Agricultural Field Berm	19	511 (80–2381)	13	5	26%	0	0%	1	5%
Channel Bank Protection	59	540 (54–5246)	9	24	41%	10	17%	16	27%
Gully Erosion Protection	6	372 (174–630)	1	3	50%	1	17%	1	17%
Road Berm	21	209 (63–2272)	19	2	10%	0	0%	0	0%
Runoff Control	14	519 (204–1240)	6	5	36%	0	0%	3	21%
Stock Tank Berm	50	246 (55–899)	35	10	20%	4	8%	1	2%
Other/ Unknown	15	432 (192–976)	7	4	27%	2	13%	2	13%

structures were noted, but not evaluated further.

4. Discussion

Landscape alteration in support of agriculture is a globally significant control on watershed processes. Ancient agricultural terraces that were abandoned centuries ago continue to influence both soil and vegetation (Stavi et al., 2018, Stavi et al., 2019). More recently, agricultural practices such as terracing have been identified as a potential threat to soil and a risk for erosion, especially if abandoned (Tarolli et al., 2014). Abandoned cultivated land and associated changes in land use have consequences for erosion, gullying, and runoff (Moreno-de-las-Heras et al., 2019). The literature describing the impacts of land abandonment on water and soil resources is dominated by studies in cultivated lands (Lana-Renault et al., 2020). We expand the scope of knowledge to include rangelands within which the primary use is often grazing. The effects of domestic grazing and pastoralism on terrestrial ecology and soil properties are well documented (e.g. Gordon and Prins, 2008; McSherry and Ritchie, 2013). However, research to quantify the effects of unmaintained or abandoned practices that support commercial grazing, such as water control and conservation structures, is in its infancy. Relative to cultivated lands, data identifying and describing the condition of such structures is sparse, thus the extent of maintenance needs and abandonment is largely unknown. Identifying and documenting water control structures and their condition are critical first steps.

Ubiquitous, but often not obvious, water development has transformed the topography of landscapes across western US rangelands. In the Altar Valley, and in many western US watersheds, present topography is the legacy of decades of earthmoving to control surface water. Construction occurred relatively rapidly over decades since the late 1800 s with new structures added in response to water supply, vegetation management, and erosion control needs. Today, structures to control runoff and sediment in support of ranching are distributed spatially over broad landscapes. Once built, these manmade structures are a primary control on drainage pathways that are altered intentionally to detain, redistribute, or store runoff, or unintentionally as re-organized runoff creates incised channels, exacerbates erosion, and desiccates lands downslope.

4.1. The context of prior land-forming processes

The interactions of manmade structures and hydrologic and geomorphic processes are complex because they occur against the backdrop of site-specific prior land-forming processes. In any setting, the influences of manmade structures occur in the context of larger scale geomorphic controls. In many valleys of the western and southwestern US, a dominant control is imparted by incising channels that create large, entrenched arroyos that are disconnected from former floodplains (Cooke and Reeves, 1976). Regional channel entrenchment and filling in the southwestern US has been cyclic over thousands of years (Emmett, 1974) with the most recent period of entrenchment in the southwest occurring between 1860 and 1900. Specifically, the Altar Valley had no well-defined channel prior to approximately 1886 (Cooke and Reeves, 1976), and historically floods traversed the valley floor as unconfined sheet flow. Today, high-velocity runoff generated during monsoon season storms concentrates within a network of incising tributary channels that connect to larger entrenched channels. Although channel entrenchment is attributed to many causes (Schumm, 1977; Graf, 1988; Webb and Hereford, 2010; Aby, 2017), Sayre (2002) hypothesized that in the Altar Valley, the failure of the Aguirre Lake dam in 1905 initiated the recent drainage pattern transition from that of poorly confined, energy dissipating sheet flows to concentrated runoff confined within entrenched channels. Currently, the Altar Wash is 4.5–10 m deep. Average channel width has increased from 66 m in 1936 to 125 m in 1987 (Sayre, 2002) and is now as wide as 400 m in specific channel reaches (Fig. 3). Once runoff is concentrated, a feedback loop develops that promotes further channel incision and bank erosion. Many of the manmade structures were built to control rangeland runoff and erosion in response to these ongoing geomorphic adjustments, however in the absence of maintenance many have become drivers of concentrated runoff, gullying, and erosion.

4.2. Structures

Construction of water supply structures began prior to entrenchment and today stock tanks are distributed relatively evenly throughout the Altar Valley. Stock tank construction increased from the 1900 s through the 1930 s and peaked in the 1950 s and 60 s after which new construction diminished (Arizona Department of Water Resources, 2009). Sayre (2007) noted that a common ratio of watering points, including dams, wells, water troughs, and earthen stock tanks is approximately one point per 1,024 ha (4 sq mi). On the Buenos Aires Ranch in the Altar Valley headwaters, the ratio reached as high as one reliable watering point per 312 ha (770 ac) just prior to establishment of the BANWR. Overall, the current density of stock tanks within the valley is one per 655 ha.

Small stock tanks are ubiquitous throughout the western US (Renwick, et al., 2005). In the state of Arizona alone more than 7,000 certificates of water rights associated with stock tanks constructed since the late 1800′s and more than 400 permits for construction of a diversion to put water to beneficial use have been issued (Arizona Department of Water Resources, 2009). An additional 850 applications are pending. The dominant hydrologic impact of the stock tanks is surface runoff capture that prevents runoff from reaching points downslope and in effect creates localized persistent drought conditions. In southern Arizona, many ranches have reduced reliance on uncertain and inconsistent surface runoff as the primary water supply by installing systems for pumping and piping to watering points. However, the stock tanks remain on the landscape. Over time, sediment accumulates in the stock tanks and behind dams, thus reducing both water storage capacity and downstream sediment yields (Nichols, 2006; Minear and Kondolf, 2009) and altering the relation between drainage area and sedimentation (Renwick et al., 2005). In addition to the direct hydrologic and geomorphic impacts of stock tanks, many have become important habitat for wildlife. For example, stock tanks in the Altar Valley support Chiricahua leopard frogs (*Lithobates chiricahuensis*), a species currently threatened by loss of habitat (US Fish and Wildlife Service, 2007) and disruptions to hydrologic connectivity (Jarchow et al., 2016). Both active and remnant earthen stock tanks pose erosion threats and the risk of habitat loss if dams, spillways, and sediment storage capacity are not maintained. In the event of a dam failure, habitats will be disrupted as both stored water and sediment are released downstream.

Earthen berms are also common in the western US. Regionally, the temporal and spatial evolution of earthen berm construction is difficult to synthesize. No common database exists, and records, if available, are spread among local offices of individual land management agencies and producers. In the upper end of the Altar Valley and within the BANWR, most water spreader berms are located on lower lying floodplains and many were constructed by bulldozer operators during floods to opportunistically reroute water (personal communication, former Buenos Aires Ranch personnel). Although this method of runoff manipulation was used in the Arivaca tributary to build spreader berms that effectively induced sediment deposition and back filled the incising channel (Sayre, 2002), today runoff is routed around or through many of the floodplain berms thus exacerbating erosion.

Outside of the BANWR, water spreader berms were constructed on upland alluvial fans, primarily on the west side of the valley to stall runoff allowing time for water to infiltrate and replenish soil moisture. Alluvial fans form under dynamic conditions of sediment transport and subsequent deposition when runoff loses stream power as it spreads across the land fan surface in distributary flows (Blair and McPherson, 1994). Dynamic re-location of drainage pathways is fundamental to fan building (Bull, 1977). Many of the upland berms that were constructed perpendicular to the general drainage direction have been bypassed (Fig. 5). Over time sediment deposits on the upslope side of the berms in response to reduced velocity of the captured runoff. As sediment accumulates, topographically higher deposits are formed, and ultimately, runoff seeks new, more efficient pathways that bypass the berms and create single concentrated flow pathways that connect to points downslope. Over time, these concentrated flow paths incise. Once incised, opportunities for drainage lateral runoff migration and fan-building are constrained. Further, structures built in series often fail in series creating connected concentrated runoff channels that traverse the landscape over long distances (Fig. 5) increasing the efficiency with which runoff is routed to primary channels, thus limiting the opportunity for infiltration to replenish soil moisture. These connected drainage pathways disrupt sediment transport and landscape scale water distribution dynamics with likely ecological consequences (Pringle, 2003; Steinfeld and Kingsford, 2013). These findings are not unlike those documented by large body of research describing the hydrologic and geomorphic processes associated with intact and abandoned terraces in cultivated agricultural lands (Arnáez et al., 2015).

Changes in drainage pattern that prevents runoff from reaching areas downslope of stock tanks and berms creates what is essentially a structure-induced drought and localized landscape desiccation. Affected areas receive rainfall, but historically many evolved under conditions of inundating seasonal flood flows that contributed to enhancing soil moisture, which is the critical limiting factor for vegetation (Noy-Meir, 1973). Even when working as intended, the benefits of water spreading are obtained at the expense of the area adjacent and downslope. Although the specific hydrologic thresholds of ecologic change are unknown in the Altar Valley, this study suggests the hypothesis that reorganized runoff is associated with changes in vegetation patterns.

Stalling lateral bank erosion is the goal of extensive and ongoing efforts in the Altar Valley to build earthen berms adjacent to steep channel banks to prevent runoff from reaching them. If the lateral channel berms fail, the entrenched channels are anticipated to widen (Schumm, 1977; Webb and Hereford, 2010). In many cases, scour through or around channel protection berms has created local points of concentrated flow and gully erosion knick points. Many of the gullies associated with breaks through manmade berms are disproportionally large and can advance rapidly in response to intense monsoon season storms (Nichols et al., 2016). However, the greatest gully head advances are not necessarily expected to be associated with the largest storms, even small storms can cause large erosion events (Delong et al., 2014). At risk are large expanses of ecologically and economically important adjacent floodplains.

Over time, manmade structures fail. Sediment accumulates on the upslope side of earthen berms creating topographic highs around which concentrated runoff flows. Sediment fills stock tanks thus reducing water storage capacity, and unmaintained dams and spillways breach and scour. All manmade structures require periodic maintenance which is often constrained by economics and neglected following land ownership or use changes. Such changes are often accompanied by the loss of local knowledge. In the decade following 1990 as many as 45% of ranches in the Rocky Mountain west were sold (Gosnell and Travis 2005). Knowledge of prior ranch operations, conservation and management goals, and purpose of associated infrastructure is easily lost, sometimes rendering manmade structures obsolete and unmaintained. This is exemplified on the BANWR where unmaintained earthen water control berms and other structures remnant of ranching days are exacerbating channel incision and erosion (Nichols et al., 2018).

Finally, managing human altered rangelands requires knowledge of the manmade structures and their impacts. Although not necessarily obvious in aerial imagery, manmade structures and their impacts on flow paths and erosion are readily detectable in the field and in recently available digital elevation models (DEMs) created from high-resolution (1 m) LiDAR data. In addition to facilitating fundamental inventories, high resolution DEMs are important for quantifying the hydrologic, ecologic, and geomorphic impacts of structures. Detailed DEMs have been used to calculate sediment loss (Lesschen et al., 2008) and quantify the hydro-geomorphic impacts of terraces (Tarolli et al., 2015). Increasing topographic data resolution is anticipated to improve both the accuracy of model simulations and land management (Preti et al., 2013). However, currently the resolution of digital elevation models commonly used in hydrologic and sediment yield simulation modeling in support of public rangeland management in the western US is 10–30 m. These low-resolution digital elevation models smooth topographic representation of the landscape such that many manmade structures and their influences are not evident or adequately represented. Thus, the spatial complexity of altered hydrologic and erosion processes is not captured. Ultimately, modeled predictions to plan for future management in human altered rangelands must be interpreted against site specific understanding of how the alterations are affecting connectivity and processes (Brierley et al., 2006).

5. Conclusion

This study of water and erosion control structures associated commercial livestock grazing in a semiarid landscape of southern Arizona, USA documents the spatial extent of manmade earthworks and provides new insights into role of humans in sparsely populated rangelands. Although human population in the Altar Valley is low and human alterations are not obvious, manmade water and erosion control structures have a substantial influence on hydrologic and geomorphic processes and patterns, especially if not maintained. Topographic modifications to alter water distribution over large landscape scales are influencing surface runoff patterns, and scour through or around structures has created both incised channels and gully erosion knick points. Even if cattle are removed from the valley, human influences will persist through the structures built to control water and erosion. These findings are not unique to the study location and have application to rangelands managed for livestock grazing in semiarid regions throughout the world where failure to incorporate the impact of manmade structures can lead to fundamentally misunderstanding of the drivers of both landscape evolution and restoration potential.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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