Case study: Facing inherited degradation and restoration concepts

San Simon Valley, Arizona, USA

Background

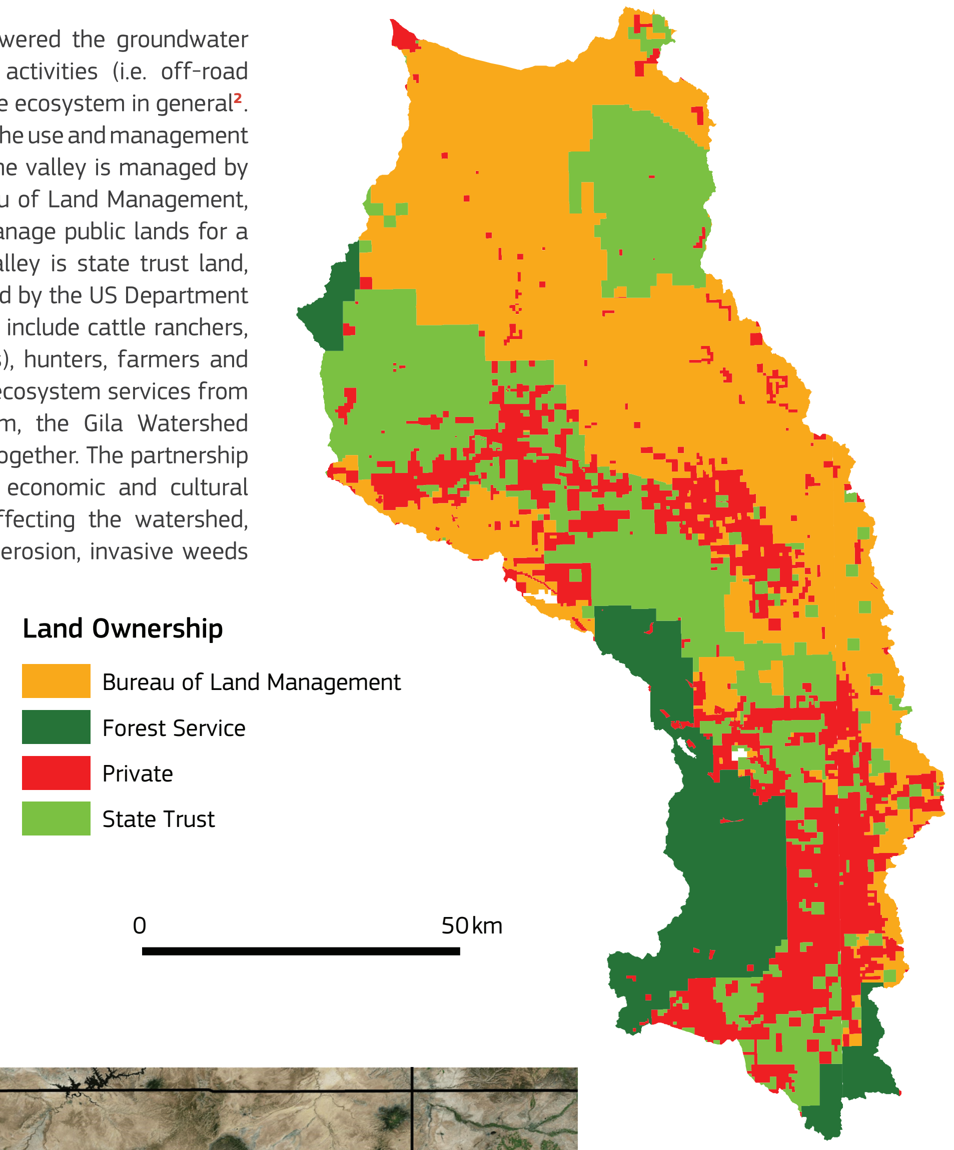
The San Simon Valley on the border of south-eastern Arizona and south-western New Mexico is one of the most dramatic examples of historical land degradation and subsequent restoration efforts in the drylands of the American south-west. The ephemeral San Simon River is a tributary of the Gila River, the major east–west river system of southern Arizona. Rising in the Black Range of south-western New Mexico, the Gila flows more than 1 000 km west across Arizona to join the Colorado River just north of the US border with Mexico. It has served as an oasis and corridor for wildlife and human settlement in an arid and semi-arid region. The lands along the main stem of the Gila have been occupied and cultivated by multiple cultures for millennia. Today, the Gila is a primary source of water for one of the most important farming areas of Arizona, the San Carlos Irrigation District.

While the San Simon is a major tributary to the Gila in terms of area — the watershed covers 580 000 ha — it contributes only 0.33 $m^3 s^{-1}$ in annual streamflow to the natural discharge of the Gila of ~54 $m^3 s^{-1}$ (of which just 6.7 $m^3 s^{-1}$ is actually discharged due to diversion and flood control). The insignificant streamflow is due to the arid climate of the watershed, with precipitation ranging from 200 mm/year in the lowlands to a maximum of 760 mm/year in the uplands. In addition to being arid, most of the watershed is flat and is composed of very fine lacustrine sediments. Valley-floor sediments have been entrenched on stretches of the river. Because of high soil erosion, the San Simon has been a major source of suspended sediment entering the Gila River, which has posed a threat to the Coolidge Dam and San Carlos Irrigation District. Vegetation cover in the valley consists of Chihuahuan-Sonoran desert shrublands in the lower portion and Chihuahuan-Sonoran semi-desert grasslands in the middle portion of the watershed[1]. Mesquite is a dominant woody species in the bottomlands and has encroached on grasslands in adjacent uplands, as a result of interplay between human (land use) and environmental factors (drought, geomorphology). This non-equilibrium system is assumed to have crossed a threshold as early as the turn of the 20th century from a grassland to a shrubland, which has persisted despite variations in rainfall and grazing pressure.

Mesquite dominance in the rangelands of the San Simon valley.
Source: Brandau, W.

Today, the major land use remains rangeland (98 % of the watershed), albeit with relatively low stocking rates compared to the cattle boom in the past. Croplands and forest are very restricted (USDA, 2007). Carrying capacity for livestock is limited as a result of historic vegetation changes and mesquite dominance. Gully erosion is widespread despite management interventions. While the pressure from livestock grazing on the land is light nowadays compared to the past, channel downcutting along the main stem of the San Simon and irrigation has lowered the groundwater table. In restricted areas, recreational activities (i.e. off-road vehicles) have put additional stress on the ecosystem in general[2].

Multiple stakeholders are involved in the use and management of the San Simon valley. Over 41 % of the valley is managed by the US Department of Agriculture Bureau of Land Management, a federal agency with the mission to manage public lands for a variety of uses. Another 26 % of the valley is state trust land, 19 % is private land and 13 % is managed by the US Department of Agriculture Forest Service. Land users include cattle ranchers, owners of ranchettes (rural subdivisions), hunters, farmers and urban populations, who derive different ecosystem services from the valley. A multi-stakeholder platform, the Gila Watershed Partnership, brings all key stakeholders together. The partnership works across physical, political, social, economic and cultural boundaries to address major issues affecting the watershed, such as water quality and quantity, soil erosion, invasive weeds and flooding.



Overview map of the San Simon Valley.
Source: Landsat 8 NASA.

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The San Simon river near Safford after a rainfall event.
Source: Ocampo, A.

History of land use

According to observations by early settlers from around 1880, vegetation conditions in the San Simon were well suited for cattle, with lush meadows covered by nutritious grama grasses[3, 4]. In 1880 a transcontinental railroad pushed across the southern tier of states in the United States and passed through much of the southern part of the Gila watershed. With access to markets to the east and west provided by the railroad, large-scale cattle operations were quickly undertaken throughout the region. By the early 1890s an estimated 50 000 cattle were grazing in the San Simon valley[4, 5]. The limited land initially granted to settlers (65 ha through the Homestead Act of 1862, until the Enlarged Homestead Act in 1909 allowed 130 ha allotments) was inadequate for any sustainable use and discouraged settlement. As a consequence, the 'open ranges' of the arid west encouraged overgrazing.

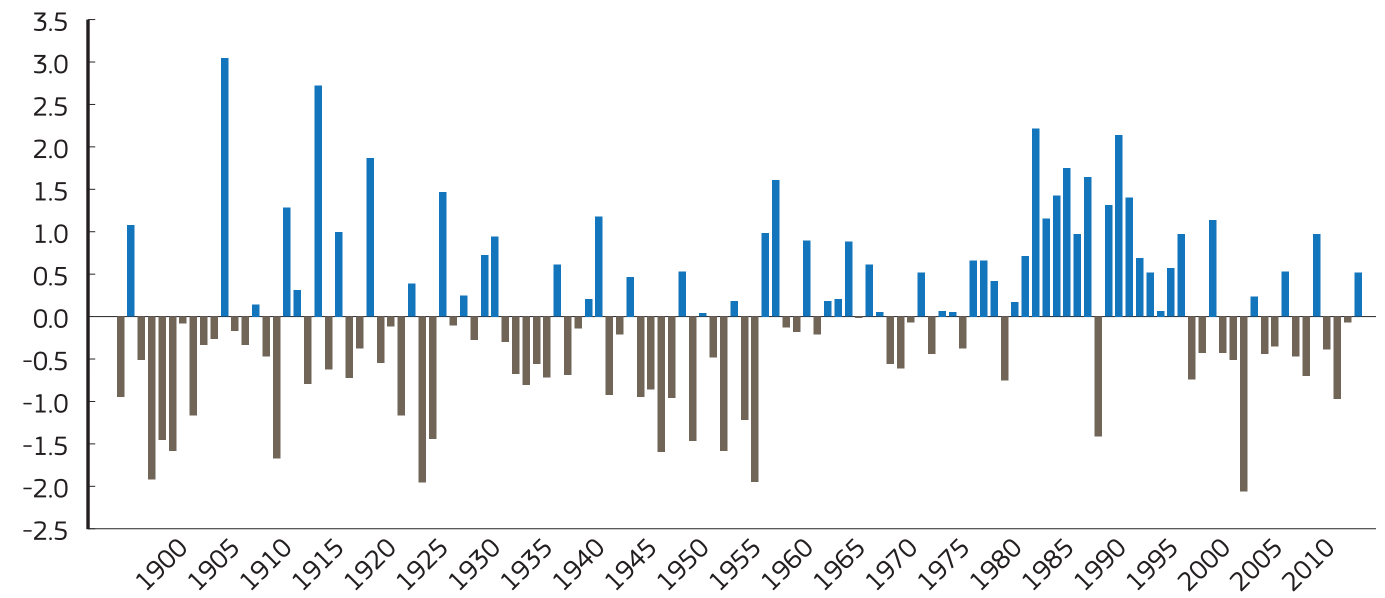
Severe overstocking led to a degradation of the vegetation cover from the 1880s onwards. Many tracts of land, often already degraded, ended up being sold to large mining and livestock companies, which also strived to obtain public lands[6]. A 'tragedy of the commons'-type situation[7], in which unregulated resources are depleted by individuals acting in their own self-interest, prevailed until more effective legal frameworks were established in the 1930s.

Cowboys herding cattle, San Carlos Apache Indian Reservation Arizona, ~1850.
Source: Arizona Historical Society.

Drought cycles and floods

Following the dramatic increase in stocking of the 1880s, the 1890s were dominated by drought. This served to further degrade vegetation and decimated the herds of livestock that relied on these largely marginal rangelands. An unusually high number of El Niño years (1887-1889, 1896-1897, 1899-1900, 1902, 1905, 1907) interrupted the droughts by bringing heavy rains to the region[8]. In a landscape largely stripped of grasses, the consequent run-off resulted in catastrophic erosion which caused the main channel of the San Simon to incise as much as 20 metres. Overall, most rainfall in this highly variable system has little geomorphological impact, but occasional high-intensity rainfall events have continued to drive gully erosion and arroyo development and sediment pulses ever since the first incision at the turn of the 20th century.

Run-off and the sediment it carried had disastrous effects on the agricultural fields downstream at the confluence of the San Simon and Gila Rivers. This sparked demand from farmers that the run-off and sediment yield from the San Simon be controlled. In 1928 the Coolidge Dam was completed 90 km downstream of the Gila–San Simon confluence to impound water that would irrigate 40 000 ha of Arizona farmland. As a consequence, sediment from the periodic floods of the San Simon not only had a direct impact on adjacent farmlands, but also threatened the function and longevity of the Coolidge Dam and the vast farmlands that it served.



Standardised rainfall anomalies in the San Simon valley.
Source: WestWideDroughtTracker (http://www.wrcc.dri.edu/wwdt/time).

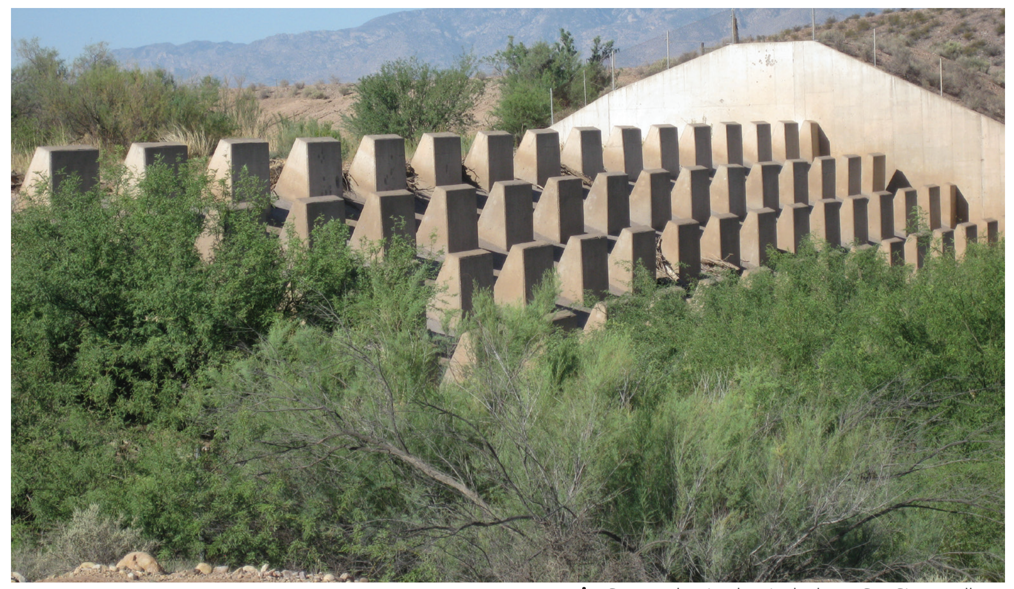
Concrete goat well drop structure. This structure transports run-off from the upper, undissected fan surface down to the current stream course, effectively stopping headward erosion.
Source: Brandau, W.

Erosion-control interventions

The US federal government responded to the demands for run-off and sediment control with intense intervention and investment in the San Simon valley from the 1930s onwards. Between 1935 and 1942 the Civilian Conservation Corps built numerous small structures to slow slope run-off on the uplands and improve vegetation cover, install small gully plugs, contour furrows and low spreaders built of brush and loose rocks[3]. Beginning in the 1930s, the Bureau of Land Management also invested in a variety of mechanisms aimed at stabilising soil and slowing erosion. The range of interventions has included:

i. construction of 19 major detention dams to control the movement of water and sediment;
ii. biological treatments (i.e. reseeding) to increase vegetation cover on surrounding uplands to enhance infiltration and reduce run-off; and
iii. management of grazing intensity to reduce pressure on scant vegetation resources[9]. The maintenance of all these structures remains an ongoing budget challenge to the Bureau of Land Management.

While the geomorphologic and vegetation changes in the San Simon were initially attributed solely to the immigration of European settlers and the open-range cattle production they introduced, these changes are now understood to result from a combination of anthropogenic (land use and management) and climatic (drought cycles) factors and positive feedback cycles among those factors.



Concrete barrier dam in the lower San Simon valley.
Source: Brandau, W.

Case study: Facing inherited degradation and restoration concepts (cont'd)

San Simon Valley, Arizona, USA (cont'd)

Gully erosion and arroyo cutting

Loss of grass cover from a combination of excessive grazing followed by subsequent drought exposed the soil to wind and water erosion. Wagon and cattle trails further concentrated flow and acted as catalysts for gully development that led to the current situation. Gully formation and arroyo cutting have remained concerns in the lower part of the valley where the impacts were greatest but have been controlled through the construction of large concrete water-control structures. The incision of the main channel resulted in the conversion of the once fertile, broad valley floor into a channel with steep banks. In the process, riparian vegetation and wildlife habitat were lost. However, these large structures have essentially stopped further downcutting. In the more gentle-sloping upper parts of the valley, comparatively modest earthen dikes have restored, to some extent, riparian function and meadow-like vegetation. For now, erosion is largely under control.

Dried vegetation along the channels.
Source: Brandau, W.

Soil loss and sedimentation

Intense rainfall events have triggered soil loss on the slopes and major sediment pulses in the San Simon. Annual sediment yield in the San Simon is high, reaching approximately 140 m^3 per square kilometre[3]. Soil accumulation behind the aging erosion-control structures poses a risk of their rupture and emphasises the need for often costly maintenance. As budgets continue to shrink for the federal agencies charged with managing and maintaining those erosion-control structures, there are more pointed questions about the ultimate value of large structures and whether or not to continue the maintenance commitment.

During flood events, suspended sediments are released into the Gila River, where they pose a threat to agricultural activities downstream, including Native American agriculture and high-value crops. The sediment load also threatens to silt up the San Carlos reservoir behind the Coolidge Dam.

Shrub encroachment

The degradation of the grass cover and the proliferation of mesquite beans fed to horses and cattle encouraged an increase in shrub cover, notably Prosopis spp. (mesquite). Mesquite, once established in a site, has superior drought tolerance and the potential to out-compete the more vulnerable grama grass cover. A positive feedback cycle of loss of grass cover, greater run-off and erosion, and increased concentration of nutrients and soil moisture leading to further loss of grass cover caused a transition from a grass-dominated to a shrub-dominated state of the ecosystem[10, 11]. This transition is generally considered undesirable for livestock because it reduces the carrying capacity of a rangeland.

It is not only livestock grazing and drought that are held responsible for this transition; fire suppression and higher than usual winter precipitation might have played a role as well. The changes in woody cover persisted even when livestock pressure was reduced: The density of woody shrubs increased threefold in a study area in the San Simon between the 1970s and 1990s, even in sites excluded from grazing[12], illustrating the complexity of the response of the ecosystem to both natural perturbations and human activities.

Erosion channels/arroyo cutting in the lower San Simon valley captured by an unmanned aerial system (RQ-11a Raven, 2012).
Source: United States Bureau of Land Management.

Expected outcome or ecosystem service trade-offs; solutions (or possible solutions)

The ongoing San Simon valley saga illustrates the enduring challenges of managing arid lands. The story began with the overstocking of very marginal grassland with livestock almost 130 years ago, which was terminated by an intense drought. When rains returned, run-off — now largely unimpeded by vegetation — was intense and the main stream channel was quickly downcut. This essentially destroyed most of the modest grazing potential in the lower part of the valley. For the next three decades, infrequent rainfall events that generated run-off carried sediments into farmers' fields at the confluence of the San Simon and Gila Rivers, affecting a large area. Despite the destruction that these events caused, significant action on the part of the federal government had to wait until the construction of a large dam to serve a 20 000 ha irrigation district further downstream. This was more than 30 years after initial entrenchment occurred. Over the next 50 years a few large water-control structures were built along the main stem of the stream, and many smaller structures were built on the uplands throughout the valley. Sediment movement out of the valley was halted, downcutting was arrested in the deeply incised lower valley and erosion was largely reversed in the less-affected upper part of the valley. While the substantial initial investment in structures has already been made, there is the continuing issue of maintenance. As budgets have contracted there is increasing pressure to scale back maintenance. The trade-offs between the costs of maintenance and the costs of addressing the outcomes of failure are unknown but are an ongoing topic of debate.

Beginning gully erosion following loss of grass cover.
Source: Brandau, W.

Convergence of evidence

San Simon Valley is mostly covered by rangeland, here intended as land dominated by shrub or grasses that supports livestock. The whole is arid and suffers from severe to extreme water stress. On 95 % of the rangeland area, these two GCIs coincide with low nitrogen balance. On around 55 % of the rangeland area, 4 to 7 GCIs coincide, adding decreasing or stressed land productivity (45 %), population change (22 %), irrigation (7 %), high population density (5 %), fires (4 %), climate and vegetation trends (3 %) or high livestock density (1 %) to omnipresent GCIs. Nowhere in the San Simon rangeland more than 7 GCIs accumulate.