Land Change Science

Beaver Dams & their Analogs *are*
Natural Infrastructure in Dryland Streams
“NIDS”

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Drivers of Change

Climate

- Winter vs. summer rainfall
- Drought→ Fire
- Monsoons→ Floods

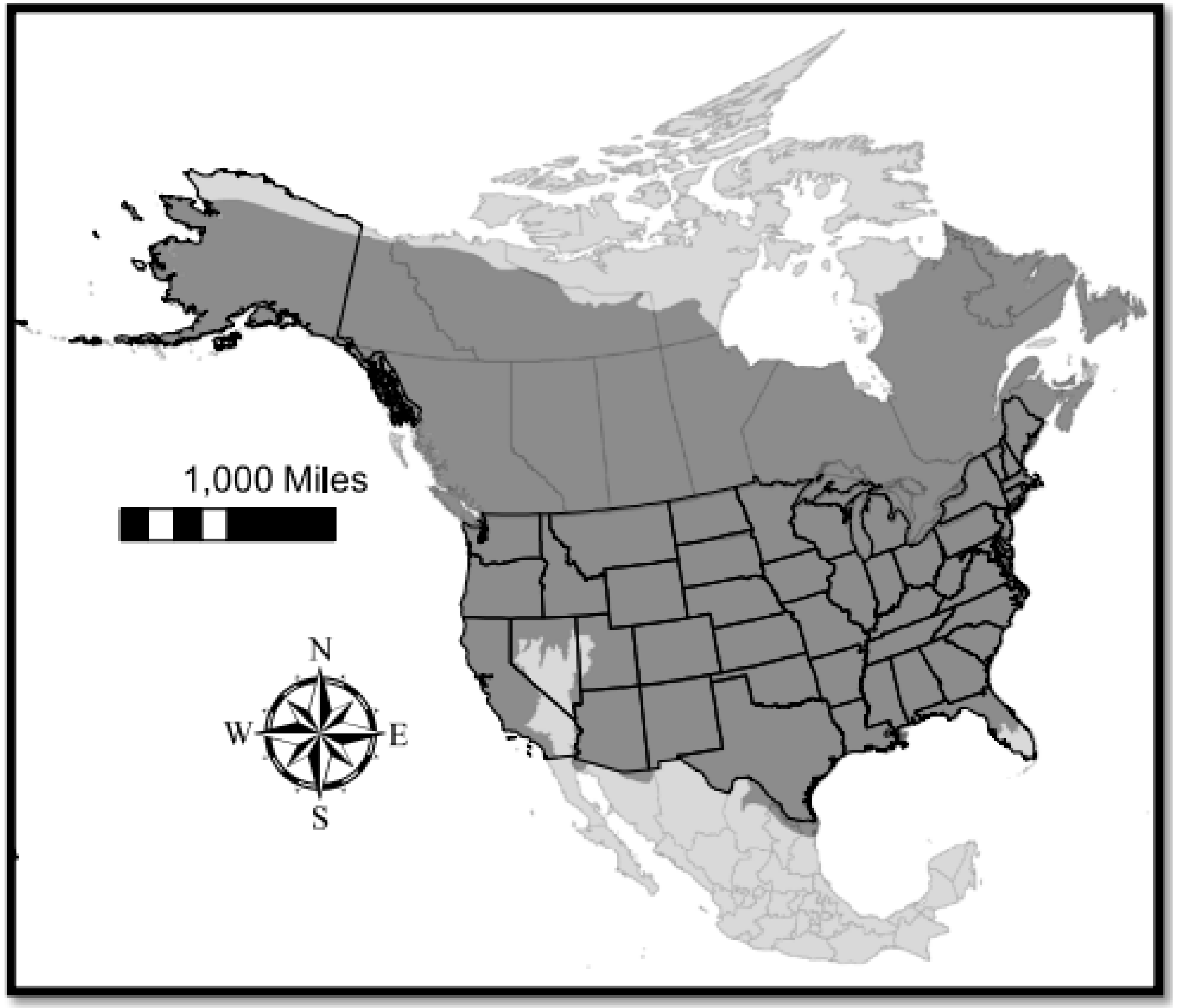
Humans

- Urbanization
- Groundwater pumping
- Agriculture
- Cattle grazing
- Timber logging
- Mining
- Fire suppression
- **Hunting, fishing, & trapping**

North American Beaver

Agents of *flood control* and *soil conservation*

https://www.sciencefocus.com/nature/why-do-beavers-build-dams/



Pollock, M. M., Lewallen, G. M., Woodruff, K., Jordan, C., & Castro, J. M. (Eds.). (**2018**). *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains* (Version 2.01). United States Fish and Wildlife Service
The Beaver Restoration Guidebook | FWS.gov

Airborne Beavers Fight Floods

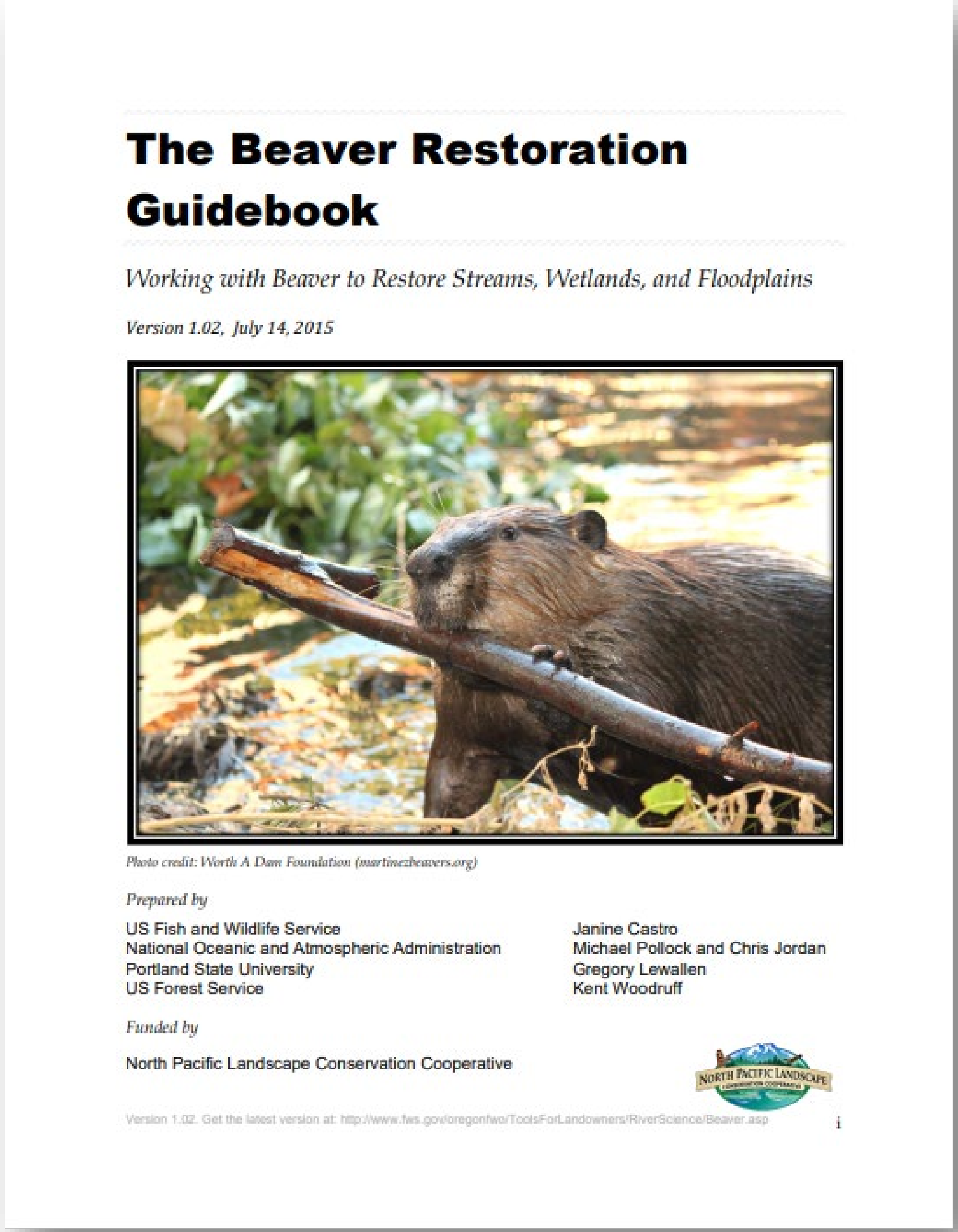
OUT in Idaho, the Department of Fish and Game is teaching eager beavers to yell "Geronimo!" These busy little creatures are being dropped by parachute to terrain where they can do their bit in the conservation battle.

Idaho state caretakers trap unwanted beavers which may be a nuisance in certain areas, round them up at central points and pack them in pairs in specially constructed wooden crates. After they are dropped, the boxes remain closed as long as there's some tension on the parachute shrouds but pull open as soon as the chute collapses on the ground. Then, out crawl Mama and Papa beaver, ready to start work.

After they're settled, the 40-pound, web-footed rodents multiply and become outpost agents of flood control and soil conservation. Fur supervisor John Smith reports that in carefully observed early operations, the beavers headed straight for water and started building a new dam within a couple of days.

However, one problem still remains to be solved—a question of ethics more than conservation. *Are these eager beavers bona fide members of the Caterpillar Club?* •

1. Boxed for travel, this beaver is placed in a crate designed by Scotty Heter, left. 2. Rubber bands pull the box apart when the chute hits the ground, freeing the animals. 3. Heading for water, the airborne beavers start working like beavers on their new dam.



The Beaver Restoration Guidebook

Working with Beaver to Restore Streams, Wetlands, and Floodplains

Version 1.02, July 14, 2015

Photo credit: Worth A Dam Foundation (martinezbeavers.org)

Prepared by

US Fish and Wildlife Service — Janine Castro
National Oceanic and Atmospheric Administration — Michael Pollock and Chris Jordan
Portland State University — Gregory Lewallen
US Forest Service — Kent Woodruff

Funded by

North Pacific Landscape Conservation Cooperative

Version 1.02. Get the latest version at: http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Beaver.asp

Pollock, M. M., Lewallen, G. M., Woodruff, K., Jordan, C., & Castro, J. M. (Eds.). (**2018**). *The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains* (Version 2.01). United States Fish and Wildlife Service [The Beaver Restoration Guidebook | FWS.gov]

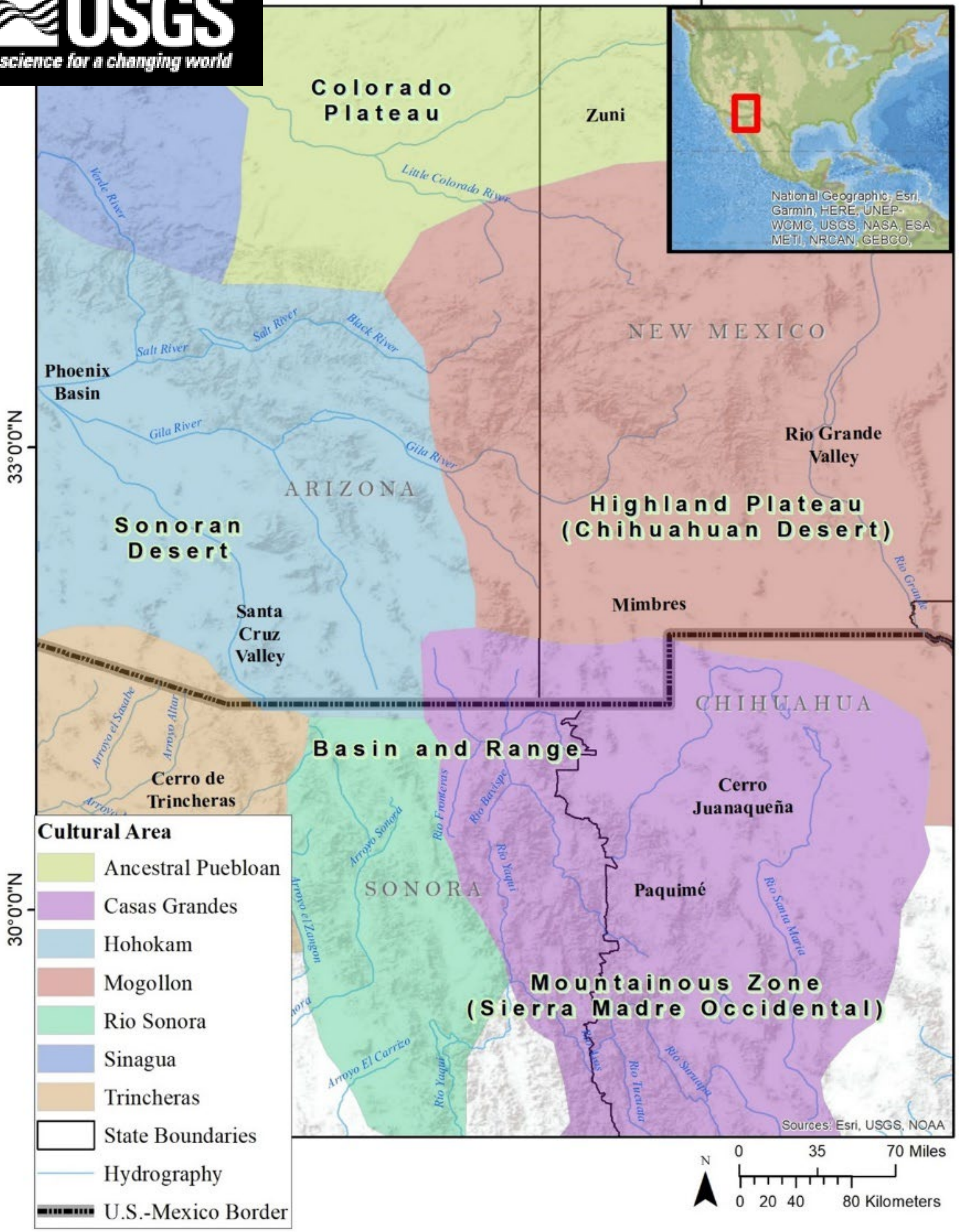
How can land- and water–resource managers reverse degradation in dryland systems to support population growth and sustainable development in a changing climate?

Photos by Valer Clark

“Rock Detention Structures”?

a.k.a.: Erosion Control Structures, Check-Dams, Gully plugs, Trincheras, Linear alignments, Leaky Weirs, One Rock Rams, Zuni Bowls, & Gabions

Ancient Infrastructure offers Sustainable Agricultural Solutions to Dryland Farming



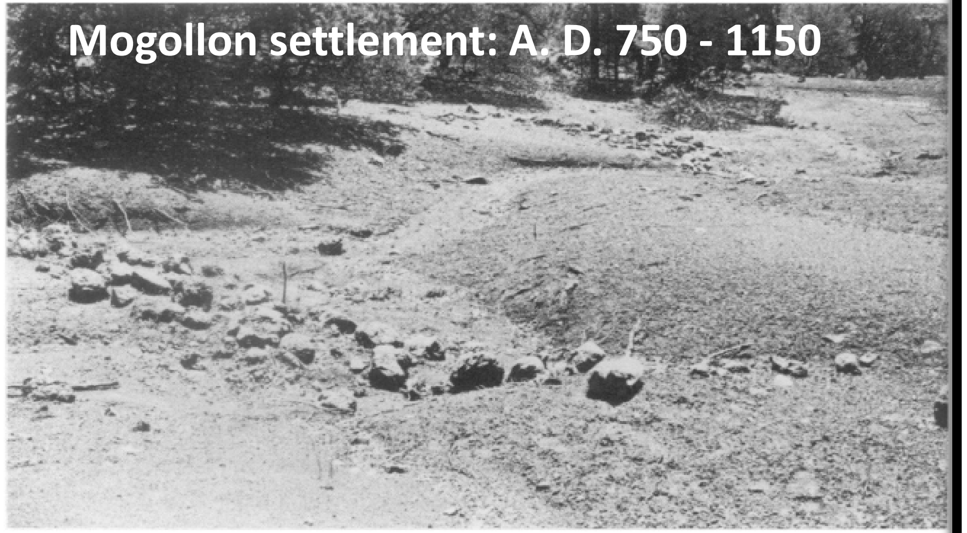


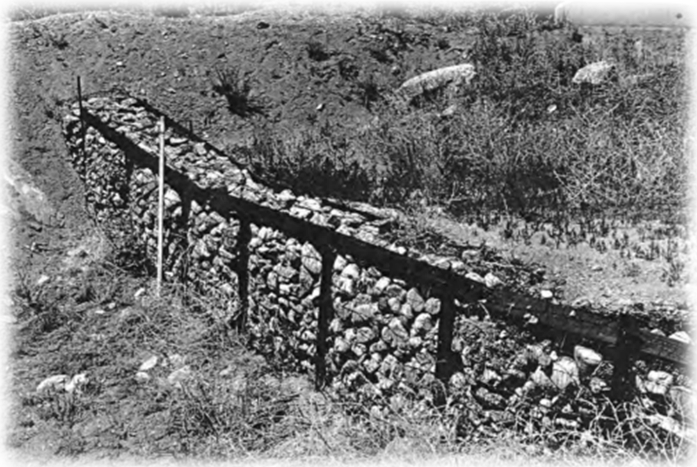
Figure 5. A Downstream View of a Series of Check Dams Breached by Erosion in the Channel along the Northern Side of Site USFS 06-04-109

Pailes, M. C., Norman, L. M., Baisan, C. H., Meko, D. M., Gauthier, N. E., Martinez, J., Dean, J., Villanueva-Díaz, J., Kessler, N. V., & Towner, R. H. (2023). Ancient Infrastructure offers Sustainable Agricultural Solutions to Dryland Farming. In *Soil and Drought: Adapting Agroecosystems to Changing Climate*. Routledge Taylor & Francis Group. https://s3-eu-west-1.amazonaws.com/s3-euw1-ap-pe-ws4-cws-documents.ri-prod/9781032286747/9781032286747c11.pdf

USGS
science for a changing world

1930's Civilian Conservation Corps (CCC)
Works Progress Admin (WPA)
Rock Detention Structures

Figure 4. Water and soil control structure built by the Civilian Conservation Corps (CCC) in the 1930s near Mogollon, New Mexico. In addition to the multiple course construction, note (1) the uniformity in the sizes of the rocks, (2) the stacking of materials that involved a certain amount of deliberation, (3) the dipped elevation, (4) the way in which rocks were stacked in the channel, abutting the banks, (5) the lack of breaching, and (6) the sediment accumulation behind the structure.



Doolittle, W. E., Neely, J. A., & Pool, M. D. (1993). A Method for Distinguishing between Prehistoric and Recent Water and Soil Control Features. *KIVA*, *59*(1), 7–25. https://doi.org/10.1080/00231940.1993.11758229

Heede, B. H. (1960). *A Study of early Gully-Control Structures in the Colorado Front Range* (Station Paper No. 55) (p. 45). Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Retrieved from http://www.fs.fed.us/rm/pubs_exp_forests/manitou/rmrs_1960_heede_b001.pdf

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Modern Rock Detention Structures






Science of rock detention structures
Aridland Water Harvesting Study

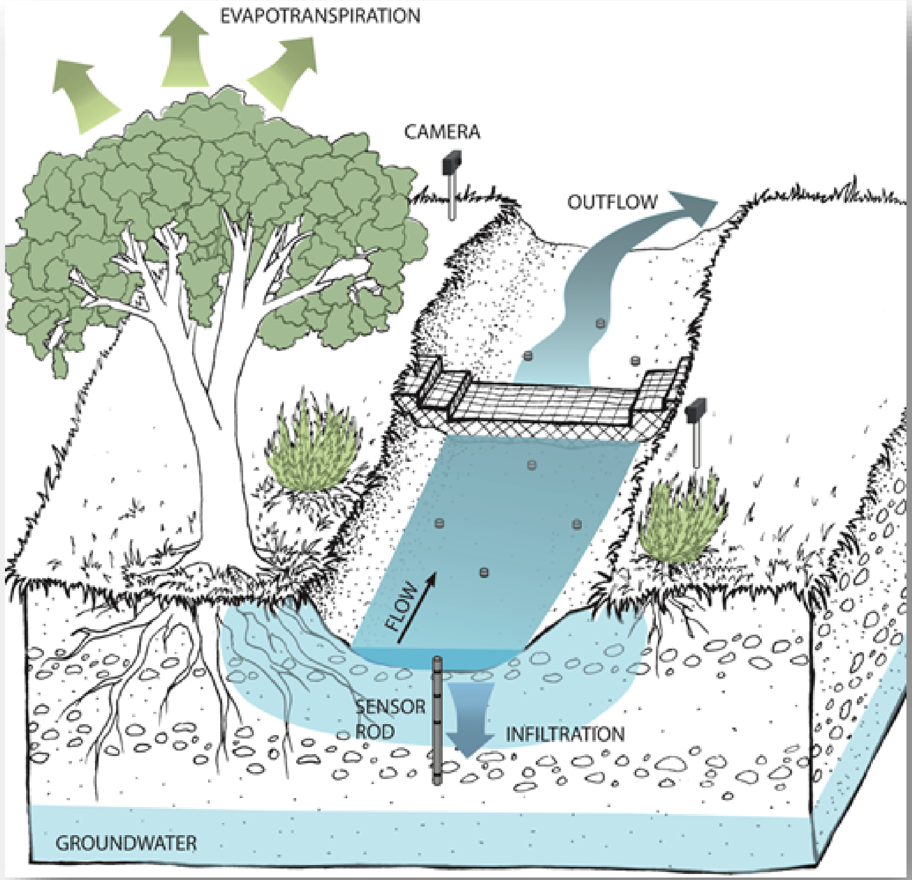
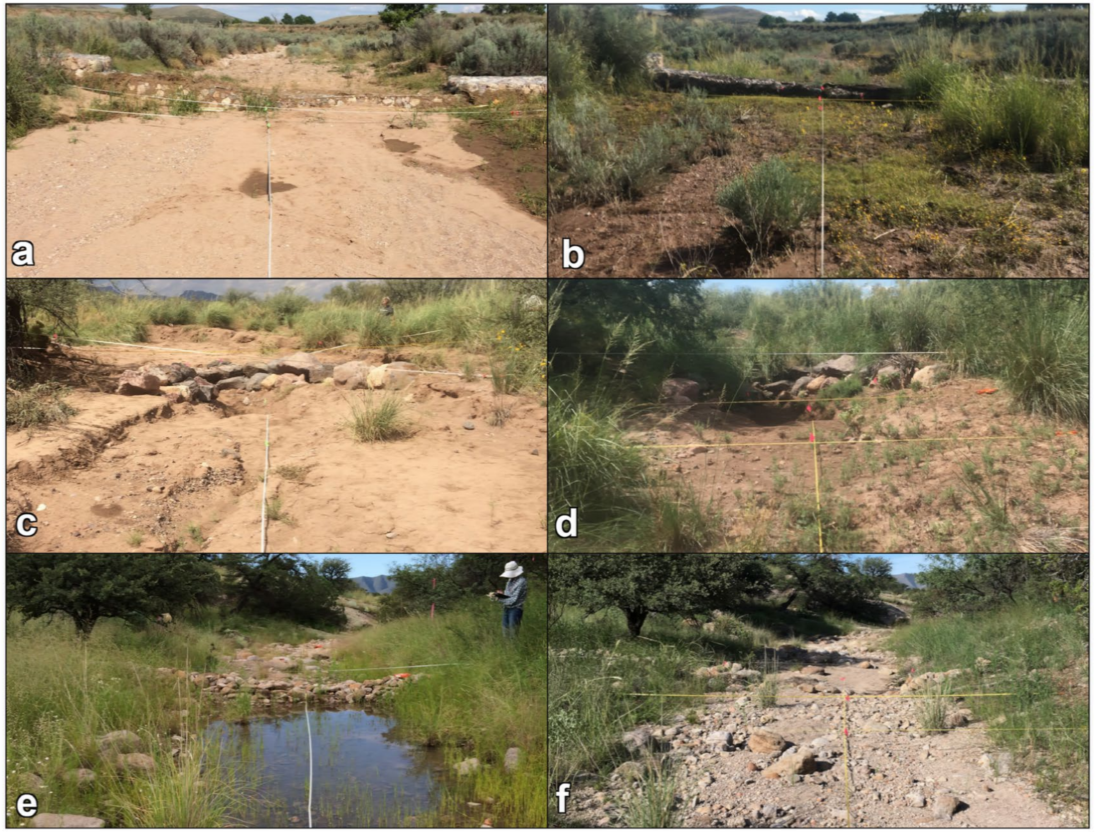


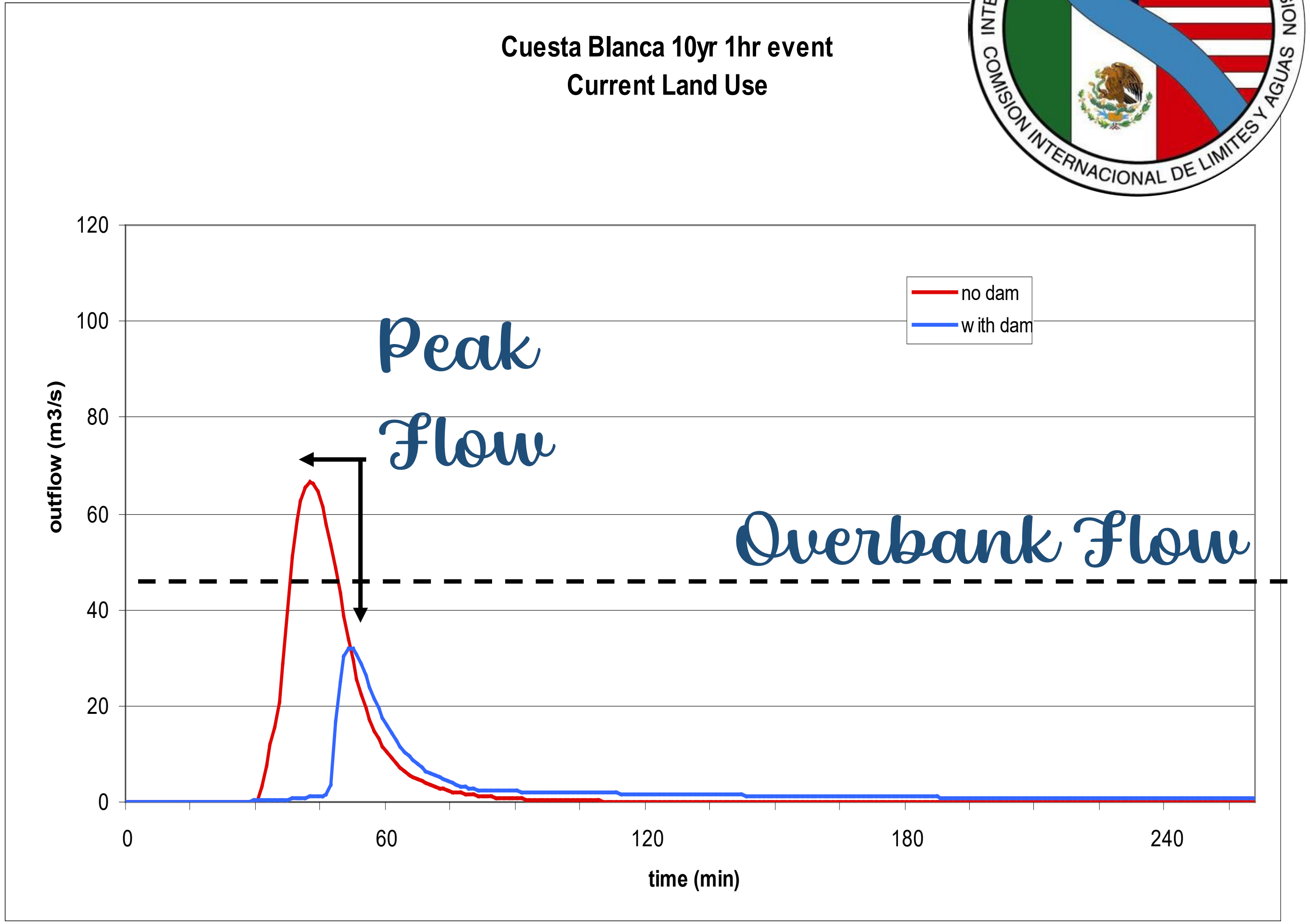
Illustration by Chloé Fandel



https://www.usgs.gov/centers/western-geographic-science-center/science/aridland-water-harvesting-study

Reduce Flooding Hazards

Gabions

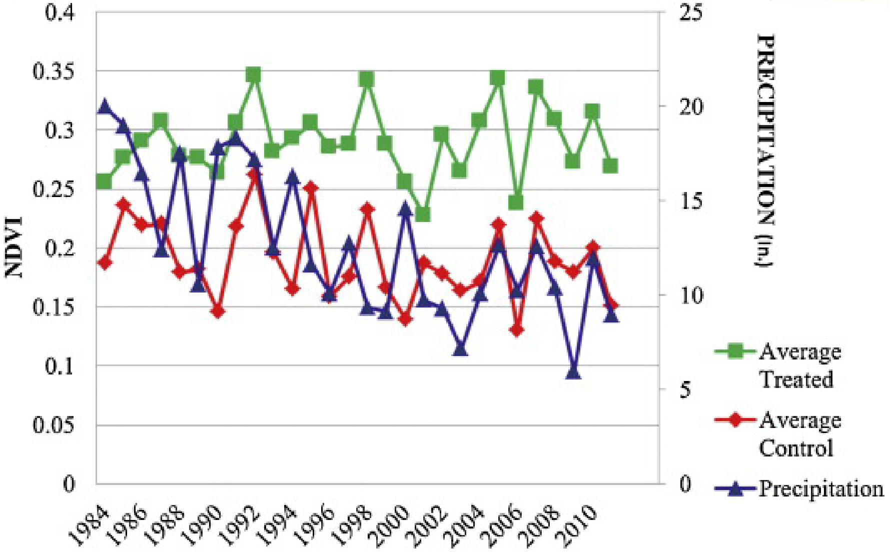


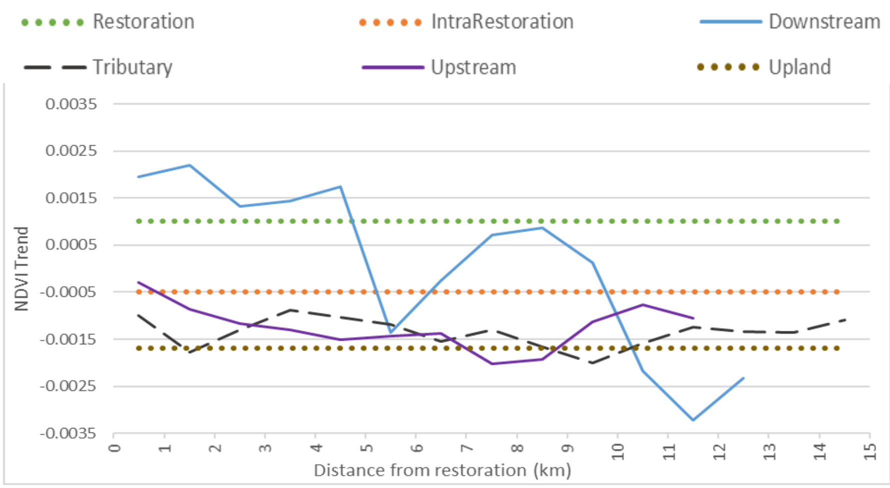
- Norman, L. M., Huth, H., Levick, L., Shea Burns, I., Phillip Guertin, D., Lara-Valencia, F., & Semmens, D. (2010). Flood hazard awareness and hydrologic modelling at Ambos Nogales, United States-Mexico border: Flood hazard awareness and hydrologic modelling at Ambos Nogales. *Journal of Flood Risk Management*, *3*(2), 151–165. https://doi.org/10.1111/j.1753-318X.2010.01066.x
- Norman, L. M., Levick, L. R., Guertin, D. P., Callegary, J. B., Quintanar Guadarrama, J., Zulema Gil Anaya, C., Prichard, A., Gray, F., Castellanos, E., Tepezano, E., Huth, H., Vandervoet, P., Rodriguez, S., Nunez, J., Atwood, D., Patricio Olivero Granillo, G., & Octavio Gastelum Ceballos, F. (2010). Nogales flood detention study. *U.S. Geological Survey Open-File Report*, *2010–1262*, 112. https://doi.org/10.3133/ofr20101262

Natural Infrastructure in Dryland Streams (NIDS)

Increase Vegetation and Habitat Provisioning

Gabions



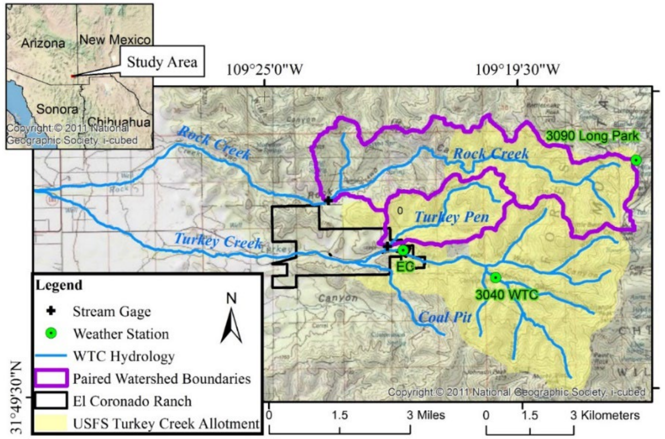


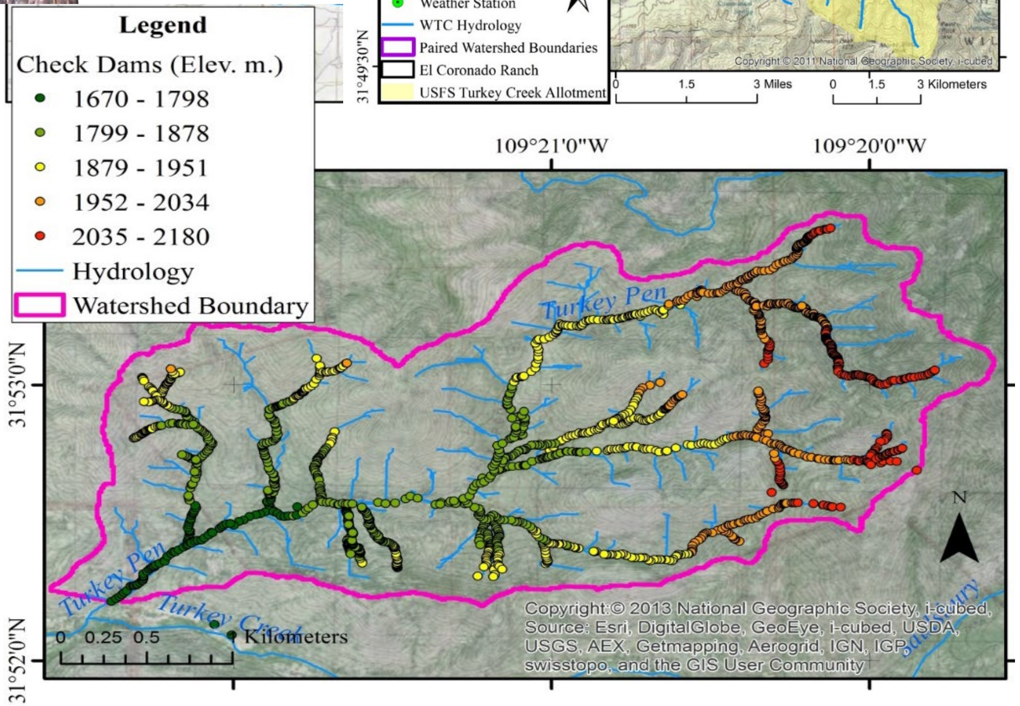
- Norman, L. M., Villarreal, M. L., Pulliam, H. R., Minckley, R., Gass, L., Tolle, C., & Coe, M. (2014). Remote sensing analysis of riparian vegetation response to desert marsh restoration in the Mexican Highlands. *Ecological Engineering*, *70C*, 241–254. https://doi.org/10.1016/j.ecoleng.2014.05.012
- Wilson, N. R., & Norman, L. M. (2018). Analysis of vegetation recovery surrounding a restored wetland using the normalized difference infrared index (NDII) and normalized difference vegetation index (NDVI). *International Journal of Remote Sensing*, *39*(10), 3243–3274. https://doi.org/10.1080/01431161.2018.1437297

Natural Infrastructure in Dryland Streams (NIDS)

- **Increase water availability**

Check Dams



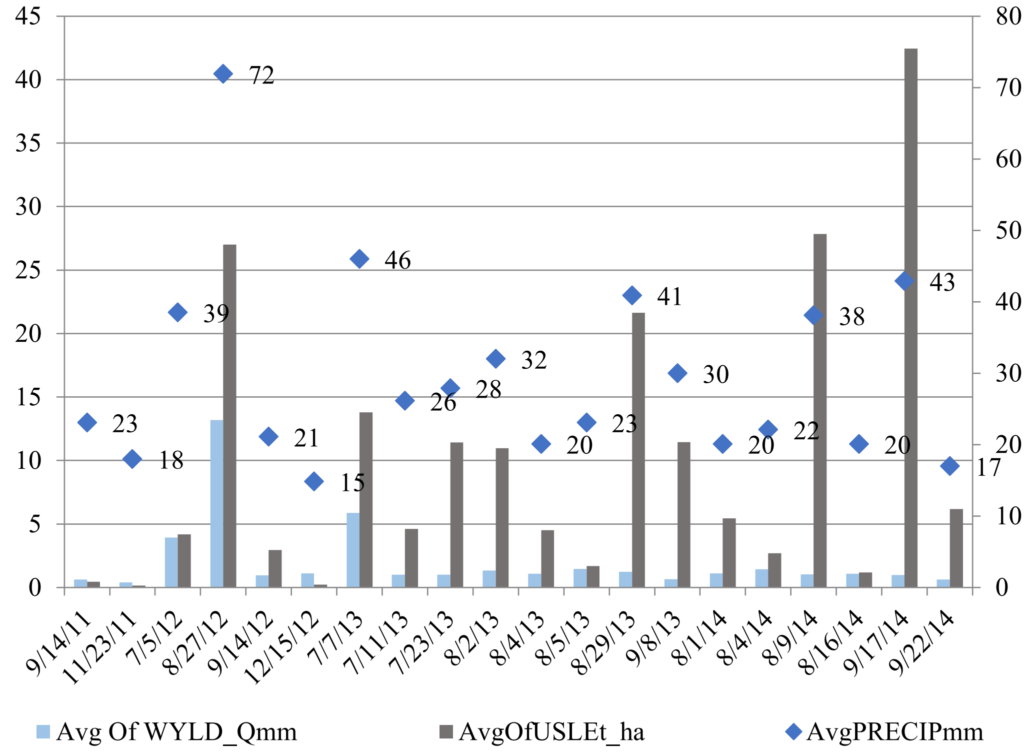


	Q Volume (Total Cubic Meters)	Precipitation (Monthly total * Watershed Size, in Cubic Meters)	% Runoff
Untreated/Control (RC)			
July	12,959	3,878,490	0.33
August	58,139	3,468,960	1.68
September	34,264	1,011,780	3.39
October	1,720	0	0
Treated (TP)			
July	0	1,238,090	0
August	18,561	1,107,360	1.68
September	27,560	322,980	8.53
October	855	0	0

Norman, L. M., Brinkerhoff, F., Gwilliam, E., Guertin, D. P., Callegary, J., Goodrich, D. C., Nagler, P. L., & Gray, F. (2016). Hydrologic Response of Streams Restored with Check Dams in the Chiricahua Mountains, Arizona. *River Research and Applications*, *32*(4), 519–527. https://doi.org/10.1002/rra.2895

- **Increase erosion control and soil formation**

Soil is **LIFE**



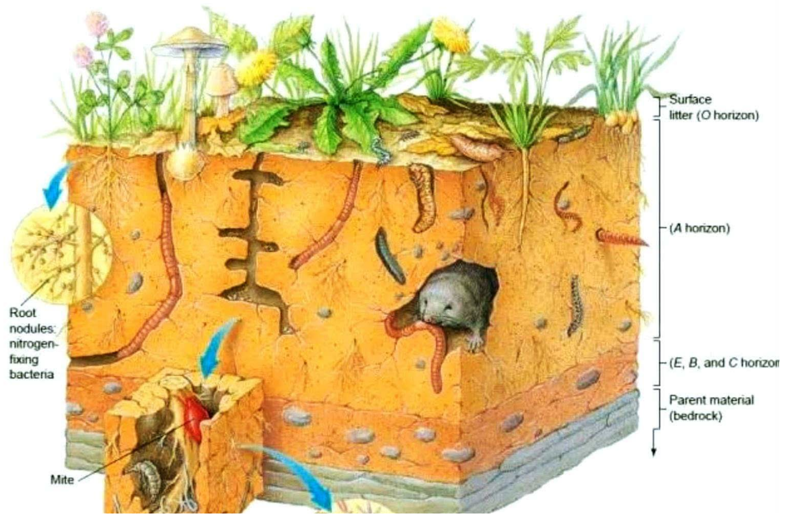


Table 2.
Model results (assuming untreated): average discharge, soil loss, and sediment yield at the study site watershed and estimates of treatment on sediment yield.

	Turkey Pen (Treated)	Rock Creek (Control)
Size (ha)	769	2405
Avg. flow (cms)	0.077	0.192
Average soil loss (USLE; tons/year)	792	3174
Avg. sediment yield (SDR = 0.45–0.61; tons/year)	356–483	1428–1936
Avg. sediment yield IF check dams (ton/year)	178–242	714–968

Norman, L. M., & Niraula, R. (2016). Model analysis of check dam impacts on long-term sediment and water budgets in Southeast Arizona, USA. *Ecohydrology & Hydrobiology*. http://doi.org/10.1016/j.ecohyd.2015.12.001

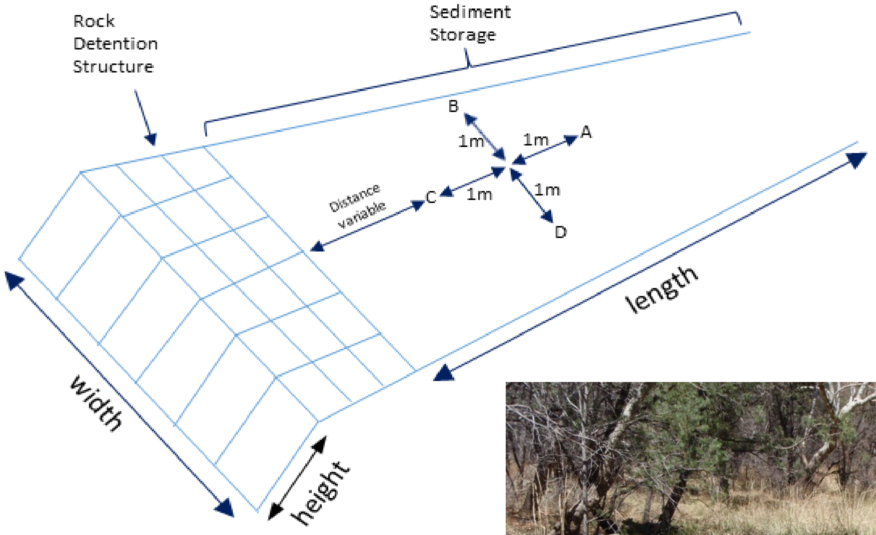
Natural Infrastructure in Dryland Streams (NIDS)

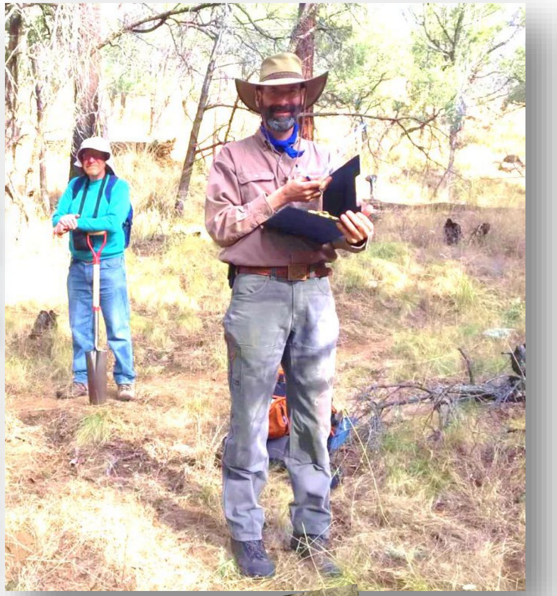
• Soil Carbon Storage and Sequestration

Trincheras

Check Dams

Gabions





Stable isotope ratios of carbon and nitrogen
(δ ^{13}C and δ ^{15}N)

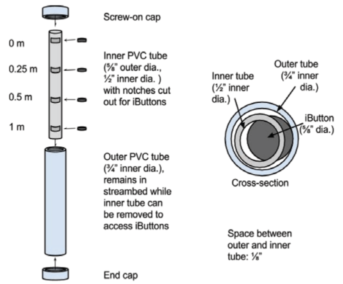
We conservatively estimated the potential mean annual capture of Organic Carbon by check dams in the Turkey Pen Watershed (recall ~>2000 check dams/769 ha) to be ~200-250 metric tons/ha.

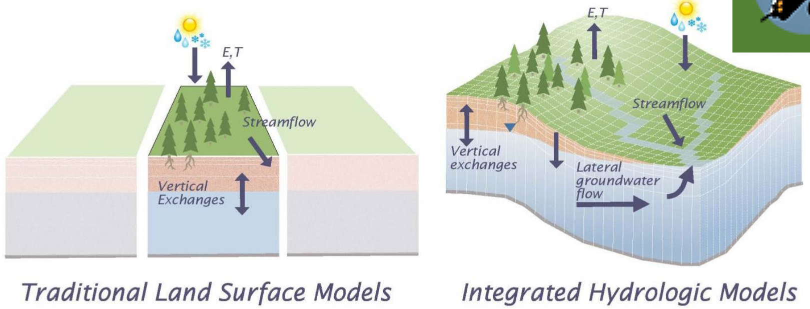
… Equivalent to what is stored in ***wetlands***

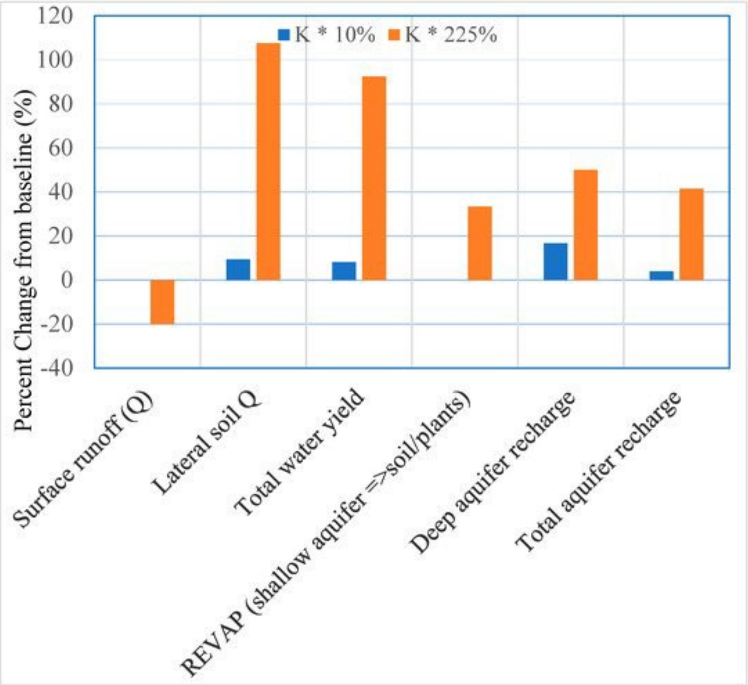
• Callegary, J. B., Norman, L. M., Eastoe, C. J., Sankey, J. B., & Youberg, A. (2021). Preliminary Assessment of Carbon and Nitrogen Sequestration Potential of Wildfire-Derived Sediments Stored by Erosion Control Structures in Forest Ecosystems, Southwest USA. *Air, Soil and Water Research*, *14*, 117862212110017. http://journals.sagepub.com/doi/10.1177/11786221211001768

- **Increase water availability (infiltration and lateral flows)**

Gabions

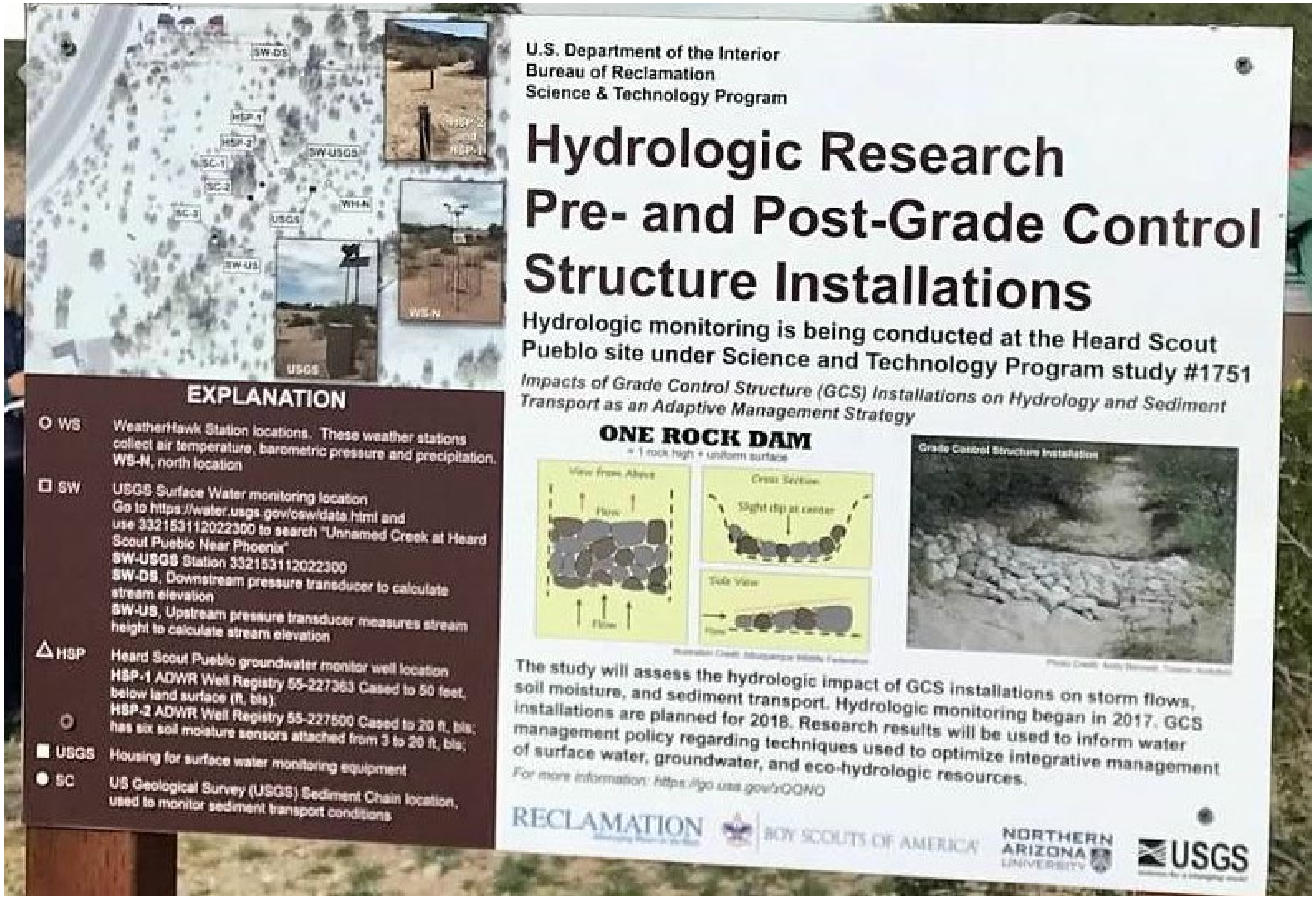






Norman, L., Callegary, J., Lacher, L., Wilson, N., Fandel, C., Forbes, B., & Swetnam, T. (2019). Modeling Riparian Restoration Impacts on the Hydrologic Cycle at the Babacomari Ranch, SE Arizona, USA. Water, 11(2), 381. https://doi.org/10.3390/w11020381

Phoenix, AZ→ Climate Regulation



One-Rock Dams

Three-degree microclimate cooling effect for at least 2 days following rainfall

- Tosline, Deborah, Norman, L. M., Greimann, B. P., Cederberg, J., Huang, V., & Ruddell, B. L. (2020). *Impacts of Grade Control Structure Installations on Hydrology and Sediment Transport as an Adaptive Management Strategy* (Science and Technology Program Research and Development Office ST-2017-1751-01). Bureau of Reclamation. https://data.usbr.gov/catalog/4414/item/6298
- Norman, L. M., Ruddell, B. L., Tosline, D. J., Fell, M. K., Greimann, B. P., & Cederberg, J. R. (2021). Developing Climate Resilience in Aridlands Using Rock Detention Structures as Green Infrastructure. *Sustainability*, *13*(20), 11268. https://doi.org/10.3390/su132011268

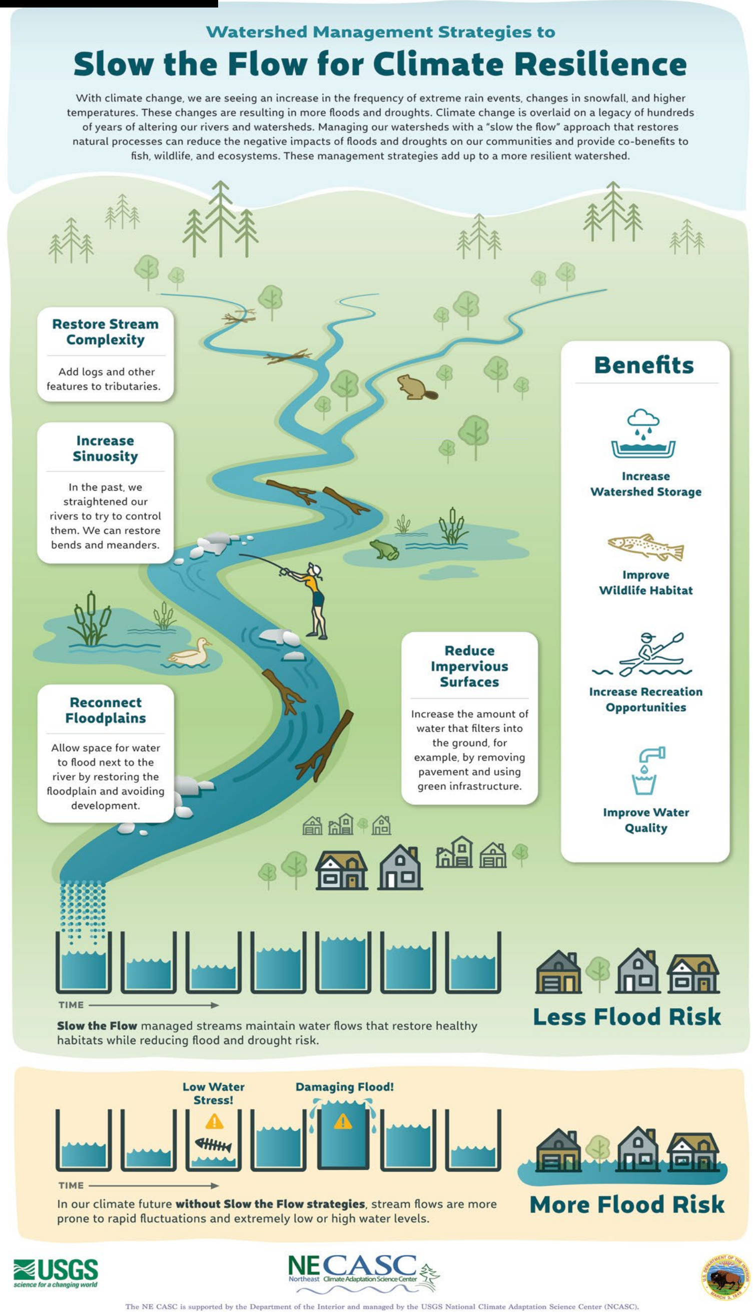
Ecosystem Services of Rock Detention Structures

- ✓Flood regulation
- ✓Habitat Provisioning
- ✓Water regulation, purification, and provisioning
- ✓Erosion regulation
- ✓Carbon sequestration and storage
- ✓Climate regulation
- ✓Food Provisioning

Norman, L. M. (2020). **Ecosystem Services of Riparian Restoration: A Review of Rock Detention Structures in the Madrean Archipelago Ecoregion**. Air, Soil and Water Research, 13, 117862212094633. http://journals.sagepub.com/doi/10.1177/1178622120946337

Ver esta publicación en español
Norman, L. M. (2020). Servicios de ecosistemas de restauración ribereña: revisión de estructuras de detención de rocas en la ecorregión del archipiélago Madrense. *Air, Soil and Water Research*, *13*, 117862212094633. https://doi.org/10.25384/SAGE.12780900.v1

Wetlands in Arid Lands!

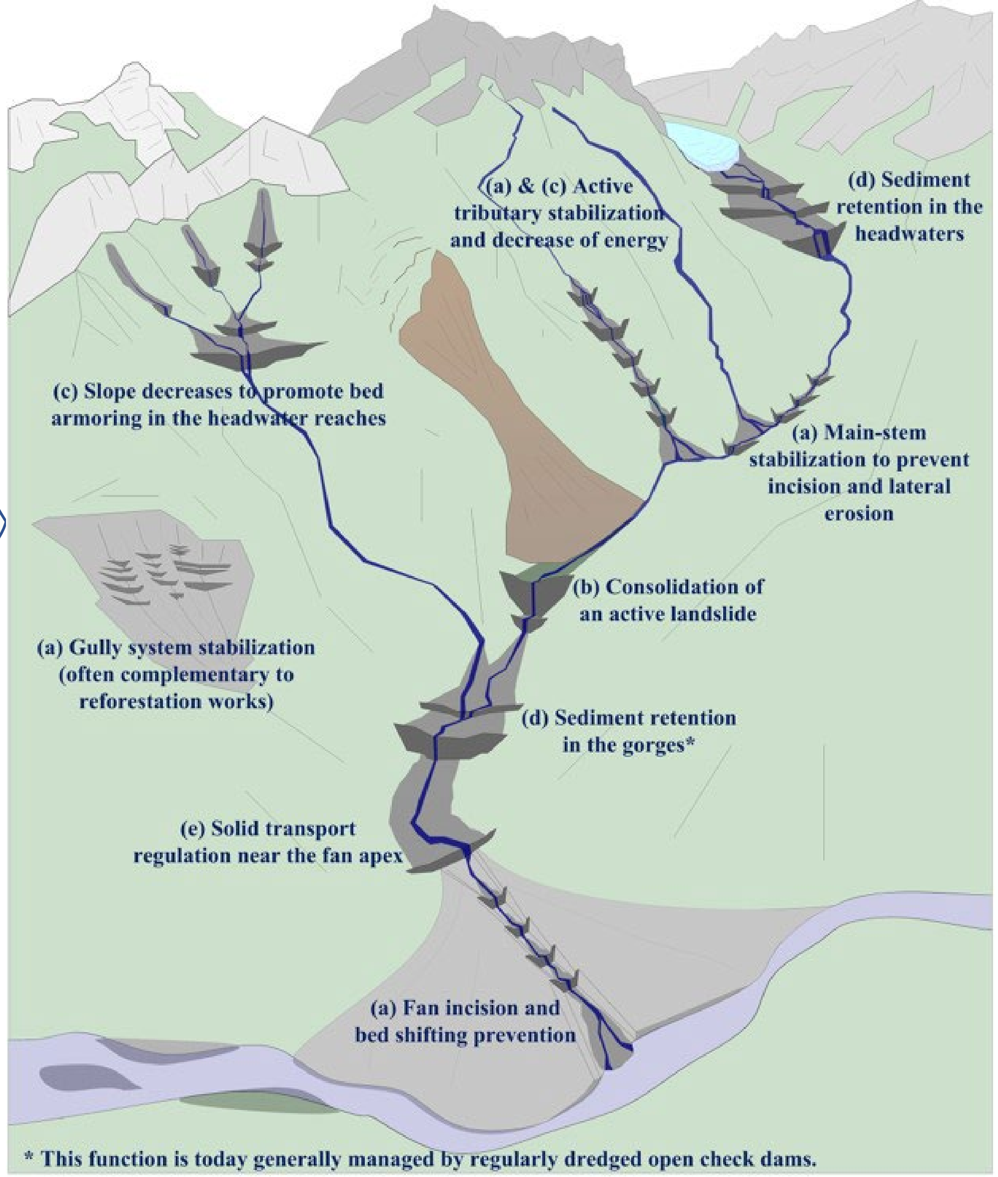


←Beavers Dams

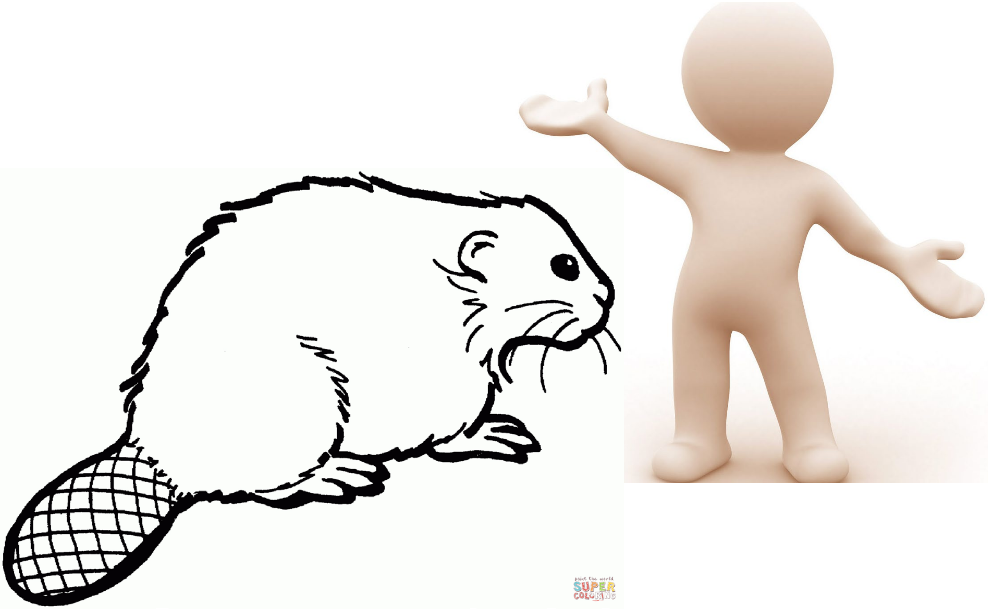
OR

Rock Detention Structures →

??

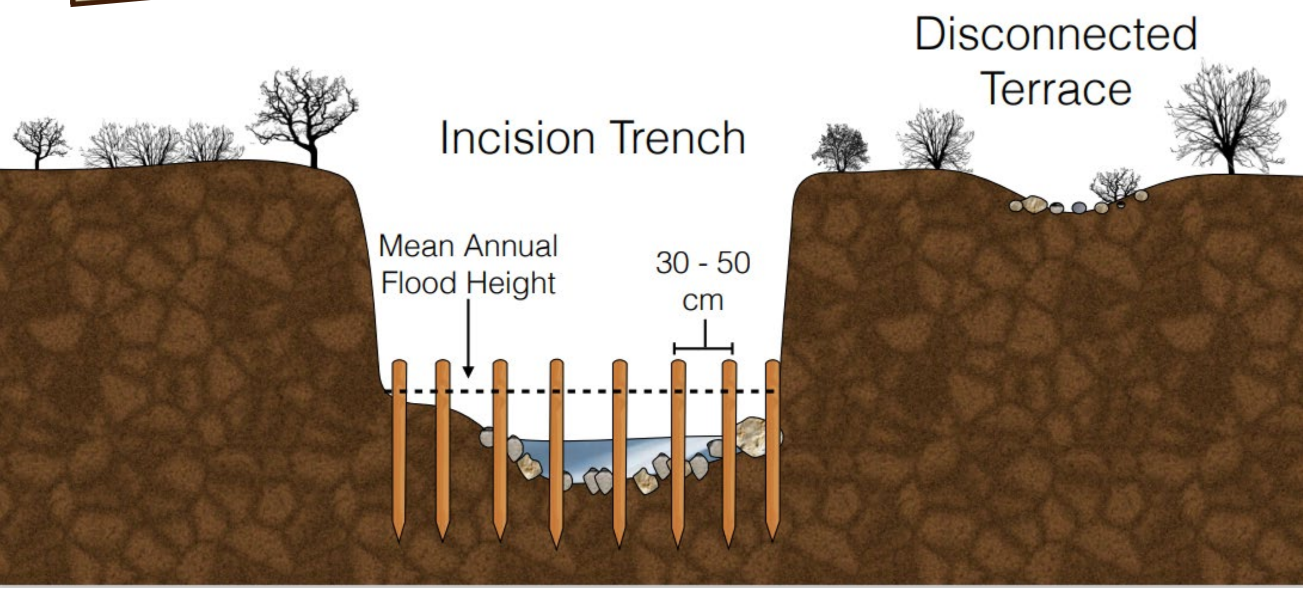


Who Done It?



https://www.sciencedirect.com/science/article/pii/S0048969722048379?via%3Dihub

Beaver dam analogues (BDAs)



Weber, N., Jordan, C., Bouwes, N., Pollock, M., Wheaton, J., Volk, C., & Wathen, G. (**2015**). *Partnering with Beavers to Recover Incised Streams—5 Years after Restoration on the Bridge Creek Intensively Monitored Watershed*. https://doi.org/10.13140/RG.2.1.1401.4160

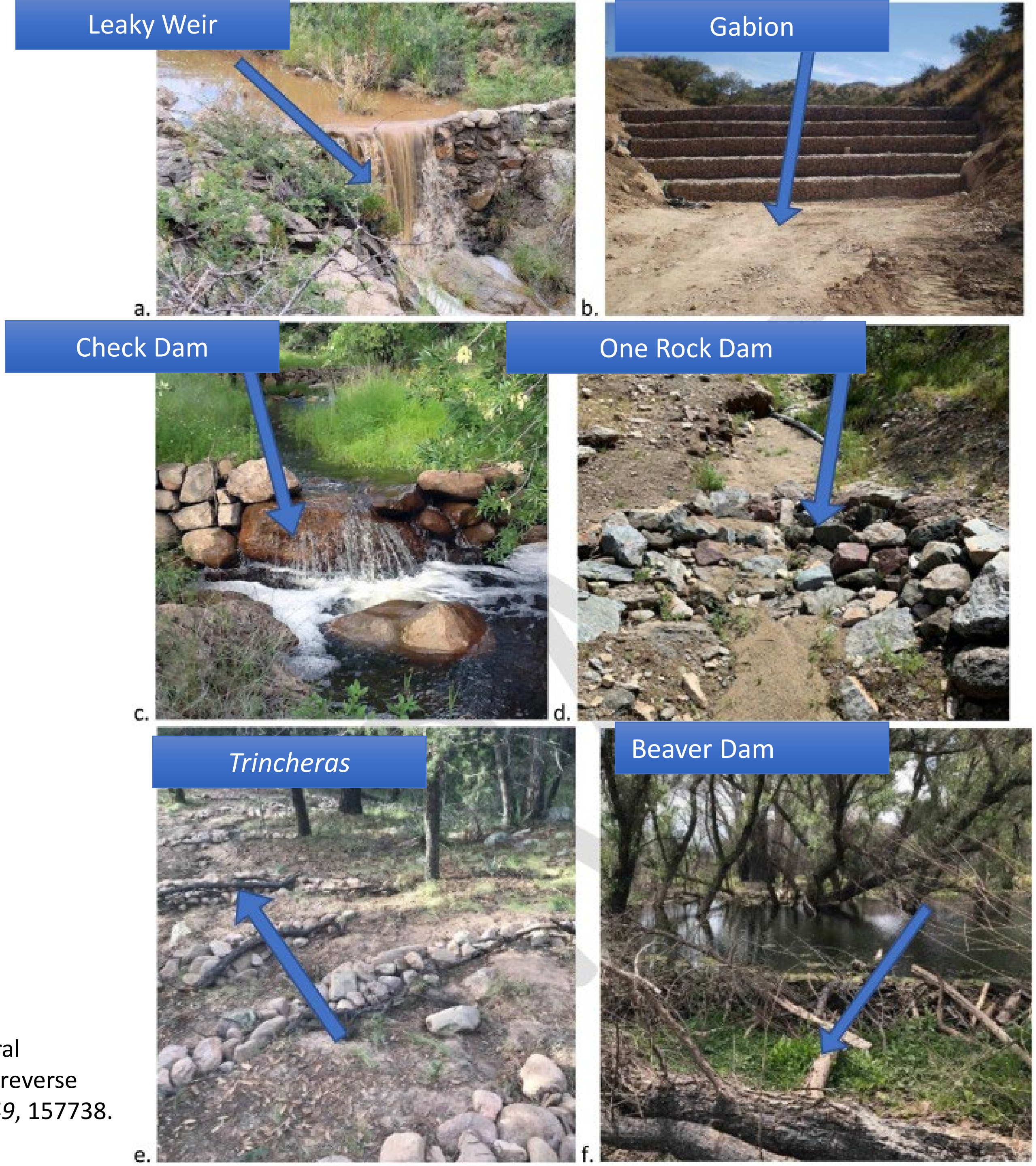
Macfarlane, W. W., Wheaton, J. M., Bouwes, N., Jensen, M. L., Gilbert, J. T., Hough-Snee, N., & Shivik, J. A. (2017). Modeling the capacity of riverscapes to support beaver dams. *Geomorphology*, *277*, 72–99. https://doi.org/10.1016/j.geomorph.2015.11.019

Natural Infrastructure in Dryland Streams (NIDS)

Beavers, Beaver Dam Analogs (BDAs)

AND

Rock Detention Structures

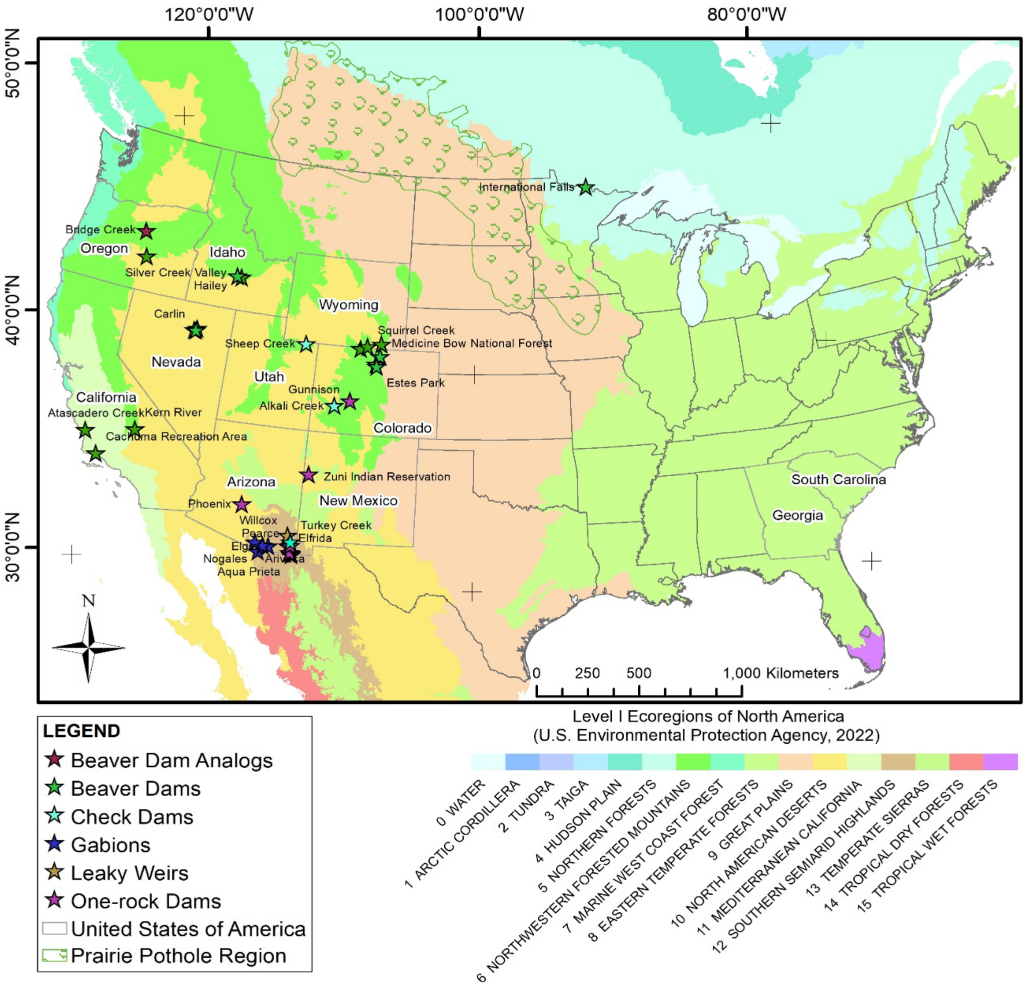


Norman, L. M., Lal, R., Wohl, E., Fairfax, E., Gellis, A. C., & Pollock, M. M. (2022). Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience. *Science of The Total Environment*, *849*, 157738. https://doi.org/10.1016/j.scitotenv.2022.157738

Natural Infrastructure in Dryland Streams (NIDS)

Soil Carbon Storage and Sequestration

Reference	Description	Place	Soil Mg C/ha
Tangen and Bansal, 2020	Prairie Pothole Region wetland (inner area)	Upper Midwest, USA	66
Buringh, 1984	Dry grassland soils	Global	40-100
Bedard-Haughn et al. 2006	Prairie Pothole Region wetland	Upper Midwest, USA	175.1
Badiou et al. 2011	Prairie Pothole Region wetland	Upper Midwest, USA	205
Callegary et al. 2021	Rock detention structure soil-water-carbon sinks	Southeast Arizona, USA	200-250
Ouyang and Lee 2020	Mangrove (tidal wetlands)	Global	283-361
Wohl, 2013	Relict beaver meadows, Rocky Mountain National Park	Estes Park, Colorado, USA	300–400
Krauuss, et al. 2018	Marsh Sites Along the Upper Tidal Estuaries of the Savannah River	Georgia, USA	455
Krauuss, et al. 2018	Marsh Sites Along the Upper Tidal Estuaries of the Waccamaw River	South Carolina, USA	1258
Wohl, 2013	Active beaver meadows, Rocky Mountain National Park	Estes Park, Colorado, USA	1150–1400



Trincheras

Check Dams

Gabions

Beaver Dams

- Norman, L. M., Lal, R., Wohl, E., Fairfax, E., Gellis, A. C., & Pollock, M. M. (2022). Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience. *Science of The Total Environment*, *849*, 157738. https://doi.org/10.1016/j.scitotenv.2022.157738

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List of climate adaptation and mitigation services for each type of NIDS

Climate Adaptation & Mitigation Services	Leaky weirs	Gabions	Trincheras and Check dams	One-rock dams	Beaver dams and analogues
Increases Water Availability	Coy et al. 2019; 2021; Norman 2021a	Fandel 2016; Fandel et al., 2016; Norman 2020; 2021a; Norman et al., 2014; 2019; Uhlman et al. 2020; Wilson and Norman 2018;	Gerencia de Restauración Forestal 2018; Heede and DeBano, 1984; Norman 2020; 2021a; Norman et al., 2016; Norman and Niraula 2016; Ponce and Lindquist, 1990	Norman 2020; 2021a; Norman et al., 2021; Silverman et al., 2019; Tosline et al., 2020	Bouwes et al., 2016; Fairfax and Small 2018; Fairfax and Whittle 2020; Gibson and Olden 2014; Gurnell, 1998; Macfarland et al., 2017; Naiman et al., 1988; Pilliod et al., 2018; Pollock et al., 2003; 2014; Puttock et al., 2017; Silverman et al., 2019; Vanderhoof and Burt, 2018; Westbrook et al., 2016; White, 1990; Wohl, 2021
Holds Sediments in Place and Promotes Soil Formation and Productivity	Coy et al., 2019; 2021; Norman 2021a	Gerencia de Restauración Forestal 2018; Norman 2020; 2021a; Norman et al., 2010a; 2010b; 2017; Norman and Niraula 2016	DeBano and Heede, 1987; Gerencia de Restauración Forestal 2018; Geyik, 1986; Norman 2020; 2021a; Norman et al., 2017; Norman and Niraula 2016; Smith and Wischmeier, 1962	Gellis et al., 1995; Gerencia de Restauración Forestal 2018; Norman, 2021a; Norman et al., 2021b; Silverman et al., 2019; Tosline et al., 2020;	Bouwes et al., 2016; Butler and Malanson 1995; Gibson and Olden 2014; Gurnell, 1998; Pollock et al, 2003; 2014; 2018; Puttock et al., 2018; Scarmando and Wohl, 2020; Silverman et al., 2019; Westbrook et al., 2016; Wheaton et al., 2019; Wohl, 2021
Stores C and N in soil-water-carbon sinks where plants grow		Callegary et al., 2021; Gerencia de Restauración Forestal 2018; Norman 2020; 2021a	Callegary et al., 2021; Gerencia de Restauración Forestal 2018; Norman 2020; 2021a; Norman et al., 2017; Norman and Niraula, 2017	Callegary et al., 2021; Gerencia de Restauración Forestal, 2018; Norman, 2020; 2021a; Silverman et al., 2019	Gibson and Olden 2014; Lazar et al., 2015; Pollock et al, 2014; Johnston, 2014; Laurel and Wohl, 2019; Silverman et al., 2019; Sutfin and Wohl, 2017; Wohl 2013; 2020; 2021
Controls stormwater runoff and filters water	Coy et al., 2019; 2021; Norman 2021a	Callegary et al., 2021; Fandel 2016; Fandel et al., 2015; 2016; Gerencia de Restauración Forestal 2018; Norman 2020; 2021a; Norman et al., 2010a; 2010b	Callegary et al., 2021; DeBano and Heede, 1987; Gerencia de Restauración Forestal 2018; Geyik, 1986; Norman et al., 2017; Norman and Niraula 2016	Gerencia de Restauración Forestal 2018; Norman 2021a; 2021b; Tosline et al., 2020;	Fairfax and Whittle 2020; Gibson and Olden 2014; Gurnell, 1998; Pollock et al, 2014; Westbrook et al., 2016; Wohl, 2021
Increases Vegetation Viability	Norman 2021a; Wilson and Norman 2019	Gerencia de Restauración Forestal 2018; Norman 2020; 2021a; Norman et al., 2014; Wilson and Norman 2018; 2019; Wilson et al., 2021	DeBano and Heede, 1987; Gerencia de Restauración Forestal 2018; Norman 2020; 2021a; Norman et al., 2014; Norman 2020; Wilson and Norman 2018; 2019; Wilson et al., 2021	Gerencia de Restauración Forestal 2018; Huryna and Pokorný 2016; Norman 2020; 2021a; Silverman et al., 2019; Wilson and Norman 2019; Wilson et al., 2021	Fairfax and Small, 2018; Fairfax and Whittle, 2020; Macfarlane et al., 2017; Pilliod et al., 2018; Gibson and Olden 2014; Gurnell, 1998; Pollock et al, 2003; 2014; Silverman et al., 2019; The Nature Conservancy 2017; Vanderhoof and Burt, 2018; Wohl, 2021
Decreases Air Temperatures and Climate Variability				Huryna and Pokorný 2016; Norman 2021b; Norman et al., 2021b; Tosline et al., 2020; Norman 2021a; Norman et al., 2021; Tosline et al., 2020; Zeedyk and Clothier 2014	Silverman et al. 2019; Weber et al. 2017

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Hydro-meteorological risks that can be addressed by NIDS as Nature-Based Solutions based on Climate Adaptation or Mitigation Strategies

Risk	Nature-Based Solution	Climate Mitigation or Adaptation Strategy	References
Drought	NIDS reduce ecosystem sensitivity to drought by enhancing soil-water capture, storage, and safe release, and by promoting vegetation productivity and diversity in soil-water-carbon sinks , this supports overall ecosystem function using less precipitation.	2.2.1. Increases Water Availability; 2.2.2. Sediment Storage, Formation, and Productivity; & 2.2.5. Increases Vegetation Viability.	Gurnell, 1998; Huryna & Pokorný, 2016; Norman et al., 2014; Robinne et al., 2021; Silverman et al., 2019; The Nature Conservancy & Gunnison Climate Working Group, 2017; Uhlman et al. 2020; Vanderhoof and Burt, 2018; Wilson & Norman, 2018.
Water Shortage	NIDS promote surface-water availability, subsurface, hyporheic flows, and recharge via capture, storage, and safe release. They increase overall hydrologic function of channels, which helps them resist reductions in water availability and helps them recover when a reduction does occur.	2.2.1. Increases Water Availability	Fairfax & Small, 2018; Fairfax & Whittle, 2020; C. Fandel et al., 2016; C. A. Fandel, 2016; Gibson & Olden, 2014; Gurnell, 1998; Norman, 2020, 2021b; Robinne et al., 2021; Silverman et al., 2019; The Nature Conservancy & Gunnison Climate Working Group, 2017; Uhlman et al. 2020; Vanderhoof and Burt, 2018; Wilson & Norman, 2018.
Flooding	NIDS help regulate small to medium sized flood events and retain NPS pollutants.	2.2.4. Flood Attenuation and Water Quality Protection.	Norman, 2020, 2021b; Norman, Huth, et al., 2010; Gurnell, 1998; Norman, Levick, et al., 2010; Robinne et al., 2021.
Heatwaves	NIDS help reduce impacts of heatwaves via increased vegetative biomass, and water content in vegetation and at rock structures, that provide cooling effects.	2.2.3. Carbon Sequestration and Storage; & 2.2.6. Decreases Temperatures and Climate Variability.	Norman et al., 2014; Wilson & Norman, 2019; Callegary et al., 2021; Norman et al., 2021; Silverman et al., 2019; Tosline et al., 2020; Weber et al. 2017.
Dust Storms	NIDS increase site and soil stability and can control a landscape's susceptibility to erosion by wind or water.	2.2.2. Sediment Storage, Formation, and Productivity.	Gurnell, 1998; Norman and Niraula, 2016; Norman et al., 2017; Smith and Wischmeier, 1962.
Wildfire	NIDS promote fire resilient soil-water-carbon sinks; they create greener/wetter riparian areas with saturated soils that are harder to ignite (firebreaks), provide refugia for wildlife, and their increased biodiversity aids in quicker recovery post-fire.	2.2.1. Increases Water Availability; & 2.2.5. Increases Vegetation Viability.	Fairfax & Whittle, 2020; Goldfarb, 2020; Norman, 2021a; Robinne et al., 2021; Silverman et al., 2019; Stockdale et al., 2019; Tensegrity, 2018; Wheaton, 2018.
Biodiversity losses	NIDS support slow-moving and clear wetland environments that provide nurseries for multiple organisms, including rare and unique plants and aquatic life. Increases in vegetation further provides opportunity of more species' habitat provisioning and forage.	2.2.5. Increases Vegetation Viability; 2.3.1. Increases Biodiversity.	Davee et al. 2019; Geist and Hawkins, 2016; Gibbs, 2000; Gurnell, 1998; Naiman, et al. 1988; Norman et al., 2014; Pollock et al., 2003; Sabo et al., 2005; The Nature Conservancy and Gunnison Climate Working Group, 2017; Vanderhoof and Burt, 2018; Wilson et al., 2016; Wilson et al., 2021; Wilson & Norman, 2019.
Food insecurity	NIDS have been used for improving food security (farming and rangeland) for over a thousand years.	2.2.1. Increases Water Availability; 2.2.2. Sediment Storage, Formation, and Productivity; & 2.2.5. Increases Vegetation Viability.	Buckley & Nabhan, 2016; Fish & Fish, 1984; Fish et al., 2007; 2013; Gilbert, 2021; Howard and Griffiths, 1966; Leopold, 1937; Norman, 2020; Wohl et al., 2019.

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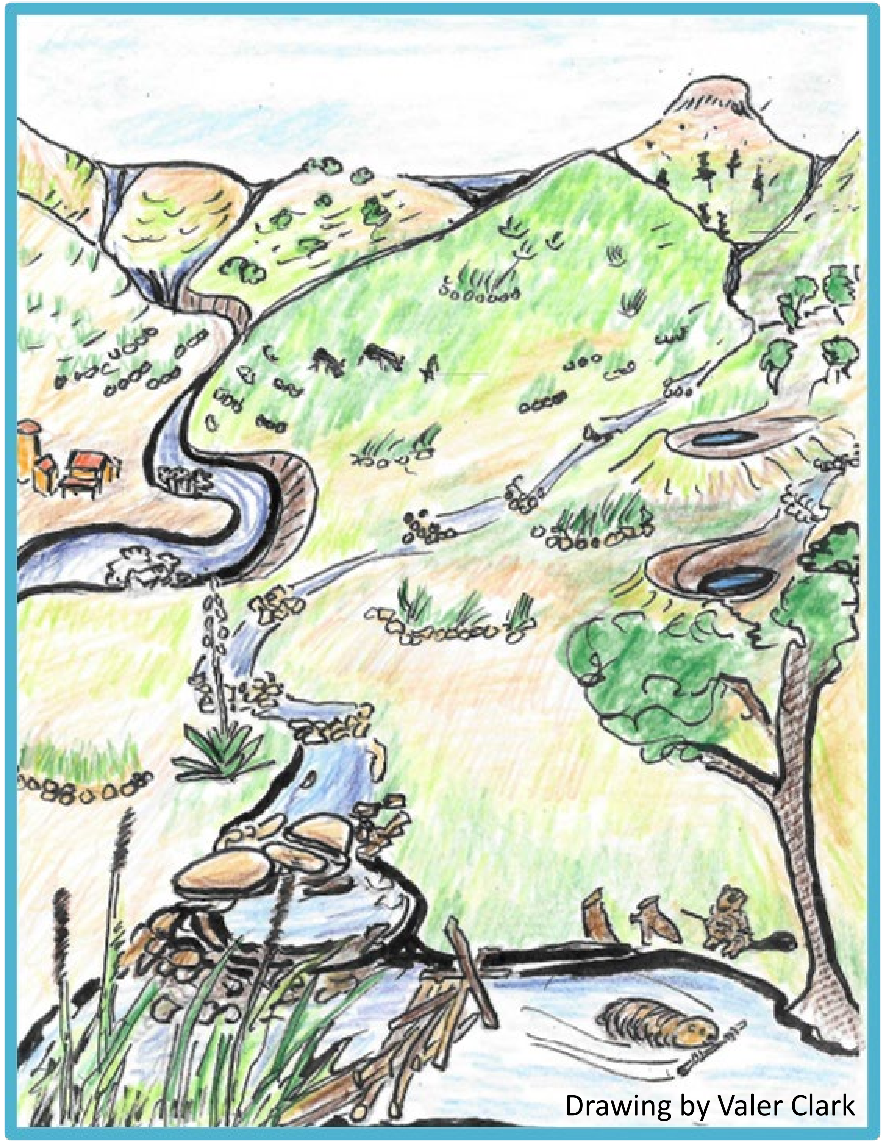
Watershed Restoration →Wetland Creation

- Long-term maintenance, adaptive management and re-tooling..
- Combination of structures, depending on conditions
- Lots and lots of structures (*thousands*)
- Installed by trained restoration practitioners
- Based on prioritized needs (erosion control, recharge, habitat provisioning, flood detention, etc..)



Drawing by Valer Clark

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Norman, L.M., Girard, M.M., Pulliam, H.R., Villarreal, M.L., Clark, V., Flesch, A.D., Petrakis, R.E., Leibowitz, J., Tosline, D.J., Vaughn, K., Wagner, T., Weaver, C., Hare, T., Perez, J.M., Lopez Bujanda, O.E., Austin, J.T., Campbell, C.F., Callegary, J.B., Wilson, N.R., Conn, J.A., Sisk, T., Nabhan, G.P., 2022. A shared vision for enhancing ecological resilience in the U.S. - Mexico borderlands: The Sky Island Restoration Collaborative. Society magazine (SERNews) 36, 19–27. https://cdn.ymaws.com/www.ser.org/resource/resmgr/sernews/sernews_36-1/sernews_vol36_iss1_vf.pdf

Nature-Based Solutions

Natural Infrastructure in Dryland Streams (NIDS)

Beavers Dams & Beaver Dam Analogs (BDAs)

USGS

Thank you!

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