Techniques for increasing watershed resilience to wildland fire

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Introduction

Wildfire impacts watersheds. The following working paper considers how scientific research and creative on-the-ground applications that merge ancient and contemporary approaches and techniques can improve both pre-event resilience, and post-event recovery outcomes.

Destabilizing ecological events such as floods and fires often combine to greatly detrimental effect in southwestern ecosystems, as shown in the typical summer monsoon tandem of lightning-caused wildfire and violent thunderstorms.

Fire is an ecosystem process managed in the contemporary western U.S. at great expense, but with mixed results—yet it is one that can be re-worked to positive effect by melding ancient burning practices with contemporary scientific findings. At the same time, the "natural infrastructure" elements of stone and wood are components of ecosystem processes whose contemporary application, when guided by ancient practices and recent research, can mitigate some of the negative effects of contemporary fire regimes.

Uncertainties abound, but so do potentials. Let's see how these processes and components can be put to work in tandem to create successful habitat restoration that is science-based, artfully-inspired, and nimble enough to work with, rather than against, ecosystem processes in mutually supportive and adaptive ways.

GEO NARRATIVE

The dual disasters of wildfire and flood are common in the Southwest. Read more about post-fire flooding in Flagstaff, AZ at the link above.

Introduction

The following discussion is part description and part prescription. It includes a range of historic and contemporary references and other resource lists, summaries of challenges, and descriptions of restorative approaches meant to inspire further inquiry into the arts and sciences of habitat restoration.

SECTION 1

The synthesis begins with basic *Definitions,* including *pre-restoration* and the *properties* and *types* of natural infrastructure work capable of mitigating the destructive effects of fire and erosion.

SECTION 2

In the next section, significant *Benefits* to ecosystems and the services they provide are noted, followed by examples of highly accessible restoration *Guides* to effective work in various habitat types.

SECTION 3

Case Studies from mainstream and Indigenous knowledge sources then highlight unique, and uniquely restorative, partnerships that have been effective in both social and ecological environments.

SECTION 4

Finally, a *Considerations and resources* section suggests how the resurgence of an ancient, yet newly refreshed and responsible ethics of care can be crafted to match the complex, multi-jurisdictional territories and sets of conditions we inhabit today.

What is natural infrastructure?

- *Watershed work before the fire*
- *Properties of natural infrastructure*
- *Types of natural infrastructure*

01

Watershed work before the fire

Restoration ecology is broadly defined as the branch of ecology concerned with how human intervention in multi-species, biotic-abiotic assemblages can mitigate damaged or destroyed ecosystems. The general understanding is that damage has been done, and that some function or component of an ecosystem might be restored in function, or even existence.

Another pathway, not entirely new but worthy of renewed attention given emergent threats today, considers the value of pre-emptively intervening in systems prior to the potentially destructive effects of fire, such as soil and species loss, and permanently reduced ecosystem function.

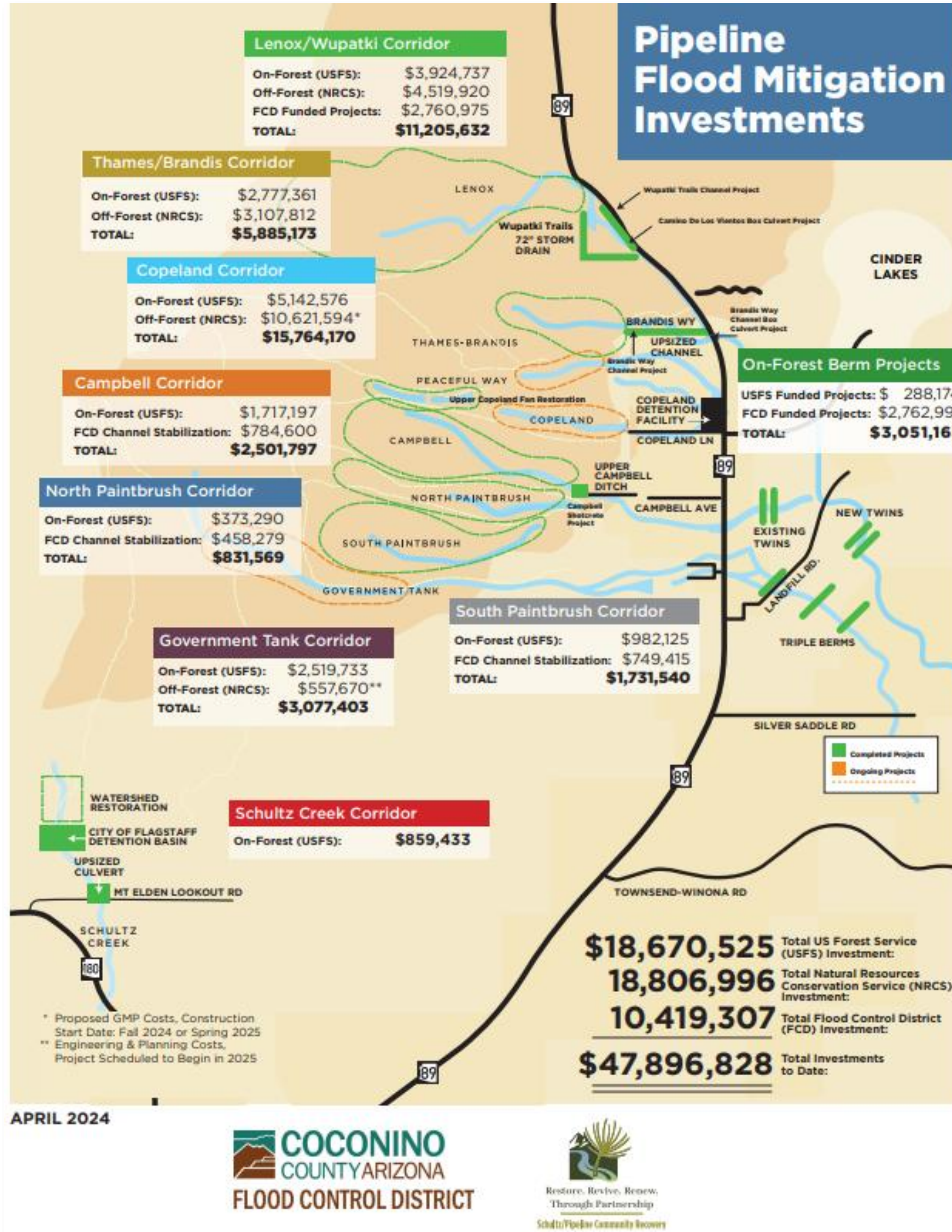
Installation of a rock structure in arid grasslands works to retain moisture in an ephemeral creek. These types of structures have shown to reduce wildfire severity.
Photo credit: US Geological Survey.

Watershed work before the fire

Through this approach and perspective, restorative work is proactive rather than reactive, and positions practitioners to avoid some of the “uh-oh” effects of large and small-scale environmental disruptions—some naturally occurring, some anthropogenic (think prescribed fires that accidentally turn wild, and the fuel loads we now face due to past fire suppression). Pre-restoration is process-based rather than relying on a single-resource, or singular mindset/response (e.g. always fight all fires aggressively). It deliberately arranges the interactions of hydrology, vegetation, and fire to increase a system’s resilience to the threats of fire and flood. The approach involves actively *participating with* existing fundamental parts and processes—not against them, and not with brute force, but with deliberation, care, and even patience. Importantly, it depends on emergent forms of collaboration and communication in fields and research offices, and with all the usual, and some unique, partners. As a practice, it potentially welds ecologies and economies together by envisioning and maintaining social systems in which people can, for example, earn their livings caring for the places they share with one another, and with myriad other interdependent species.

Structures can be installed in natural streams (left) and in urban places (right) to slow water down to increase ecosystem resilience.
Photo credit: Cuenca los Ojos (left); Stream Dynamics (right).

Watershed work before the fire



CASE STUDY: Coconino County

The costs of post wildfire flood mitigation efforts from a single fire in Coconino County. Many of the techniques being used to protect neighborhoods carry large impacts to the watershed. Find out more information at the link above.

Properties of natural infrastructure

Many in the natural infrastructural-science community today embrace the possible avenues of creativity along with the need for careful application of natural infrastructure use in pre-restoration. For example, scientists from the USGS and the Bureau of Reclamation are in many ways now on the front lines of pairing theory and practice, data collection and restorative action. They have called such work an "adaptive watershed management alternative for climate change" (Tosline 2016), and a "natural infrastructure" application akin to the work of beavers (Norman 2022a) for the stability, predictability, and resilience they contribute to a system.

Stone and wood are sometimes termed "natural infrastructure" (Norman et al. 2022a), but other researchers, practitioners, and funders use terms such as erosion control structures (ECS), rock detention structures, engineering with nature (EWN), and nature-based solutions (NBS). In total, these concepts continue to contribute to a growing field of restorative practice often labelled *low-tech process-based restoration*.

DESIGN MANUAL

Low-Tech Process Based Restoration of Riverscapes Design Manual

Rocks stacked in Cienega Creek in Southeastern Arizona. There are two installations in this image; can you see the one in the far back?

Photo credit: US Geological Survey.

Properties of natural infrastructure

Generally, the structures under consideration hold the following properties:

- They are built from locally available rock and wood, with the latter often resulting from a repurposing of material from fuels reduction projects (think “rearranging the furniture”); and without removing wood or stone already embedded in the ground, and therefore already “at work” holding soil and reducing erosion.

- They are built low, like horizontal walls, with each piece tightly fit with others to reduce gaps, while still allowing water to slow, rest, and pass through and over without causing turbulence or end-cutting.

- They mimic channel morphology and are keyed into channel banks for stability or are built on contour on gentle slopes to capture water and sediment, and slow flow rates. In short, they are designed to participate with the existing form and function in place and provide supportive material as “nudges” to processes or features under stress, or soon to be.

METHODS VIDEO

After wildfire, drainages can become highly eroded. This video demonstrates a small project in Arizona grasslands. These techniques can be used anywhere. Click the link above to learn.

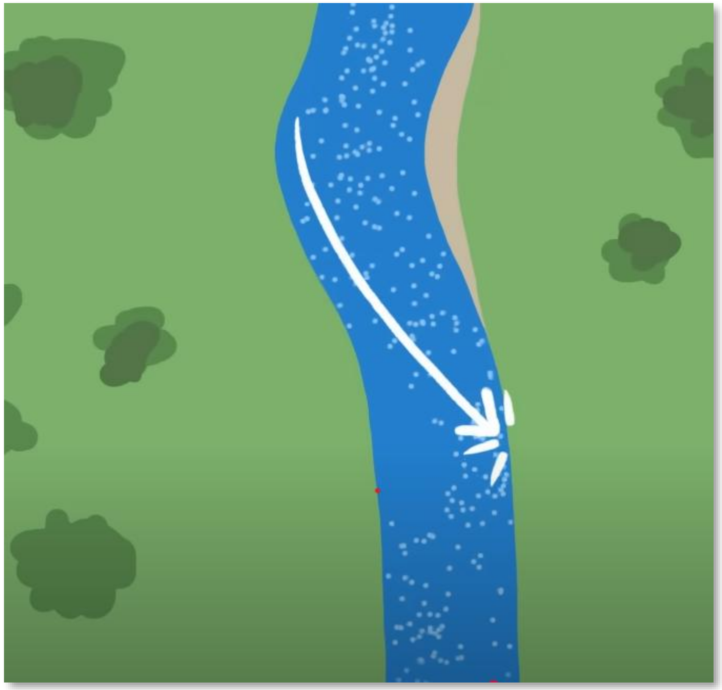
Photo credit: Modest Maker.

Types of natural infrastructure

There are many types of erosion control structures. These can be built with many on-site materials, typically rock or wood. Structure types depend upon application and system needs. Some of the most common types exemplified in the field guides below are:

Baffles and post vanes—arranged on alternating sides of a channel to induce meanders, and thereby lengthen a channel and slow velocity and erosive force.

Post vanes on the far (upper right) channel work to induce the meander of this creek, keeping it from eroding into the field beyond. This technique can be used to protect roadways and other infrastructure.
Photo credit: David Seibert.



[LEARN: Why do rivers curve or meander?]
Understanding this concept is the foundation for a lot of watershed work. Click the link above for a quick tutorial about stream meandering.

Types of natural infrastructure

One-rock structures—constructed "riffles" in channels to increase roughness and heterogeneity while arresting down-cutting that pulls moisture out of systems.

Simple rock structures working to rebuild channels. Photo credit: Molly McCormick.

Types of natural infrastructure

Head-cut bowls—armored faces of leading head-cuts that arrest spill-over erosion and the uphill "unzipping" of slopes and meadows; best applied with a one-rock structure immediately below and a media luna or rock contour line above.

Zuni bowl arresting erosion of a head cut in an Arizona grassland.
Photo credit: David Seibert.

Zuni bowl arresting erosion of a head cut in a New Mexico wetland.
Photo credit: Watershed Artisans.

Types of natural infrastructure

Log mattress — Used as a protective cover to arrest erosion and stabilize banks, logs or brush are laid down across an erosional feature.

WATCH A DOCUMENTARY: Restoration of Santa Clara Canyon

LEFT: Log mattresses arranged in a step-down fashion to reduce erosion in a watershed affected by wildfire.

Photo credit: Erick Gonzalez.

Types of natural infrastructure

Beaver pond/Beaver Dam Analog - used to slow water and create wetland habitat by either mimicking the ponding done by beaver or attracting beaver to the location.

Fire refugia created by a beaver pond. Photo credit: Emily Fairfax.

Reconstructed beaver pond at Santa Clara Pueblo.
Photo credit: Erick Gonzalez.

TRAINING: Low-tech process-based restoration of riverscapes
Free learning modules and resources from Utah State University.

Benefits of natural infrastructure?

+ *Reduces fire effects*
+ *Increases soil hydraulic properties*
+ *Increases complexity and resilience for social, ecological and economic benefits*

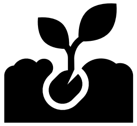
02

Benefits of natural infrastructure

Basic functions of wood and stone installations include:

1) SLOW: reducing water's speed and erosive force, especially when fire eliminates vegetation and rains quickly follow;

2) SINK: increasing moisture infiltration and availability by increasing its duration on site; and



3) JUMP START RESTORATION: capturing seeds and other organics in place, when they tend to be the lightest, and therefore the first materials washed away by overland flows.

BUT THAT'S NOT ALL: People have long understood these threats and restorative benefits, and have responded in remarkably similar ways to them, as described in archaeological literature documenting work installed thousands of years ago (Pandey et al. 2003; Sandor et al. 2000; Woodbury 1960). After more than 15 years of intensive research by academic and federal agency geologists, hydrologists, and restoration practitioners (see References), we know that there are robust, repeated scientific indicators that natural infrastructure have many other benefits.

Benefits of natural infrastructure

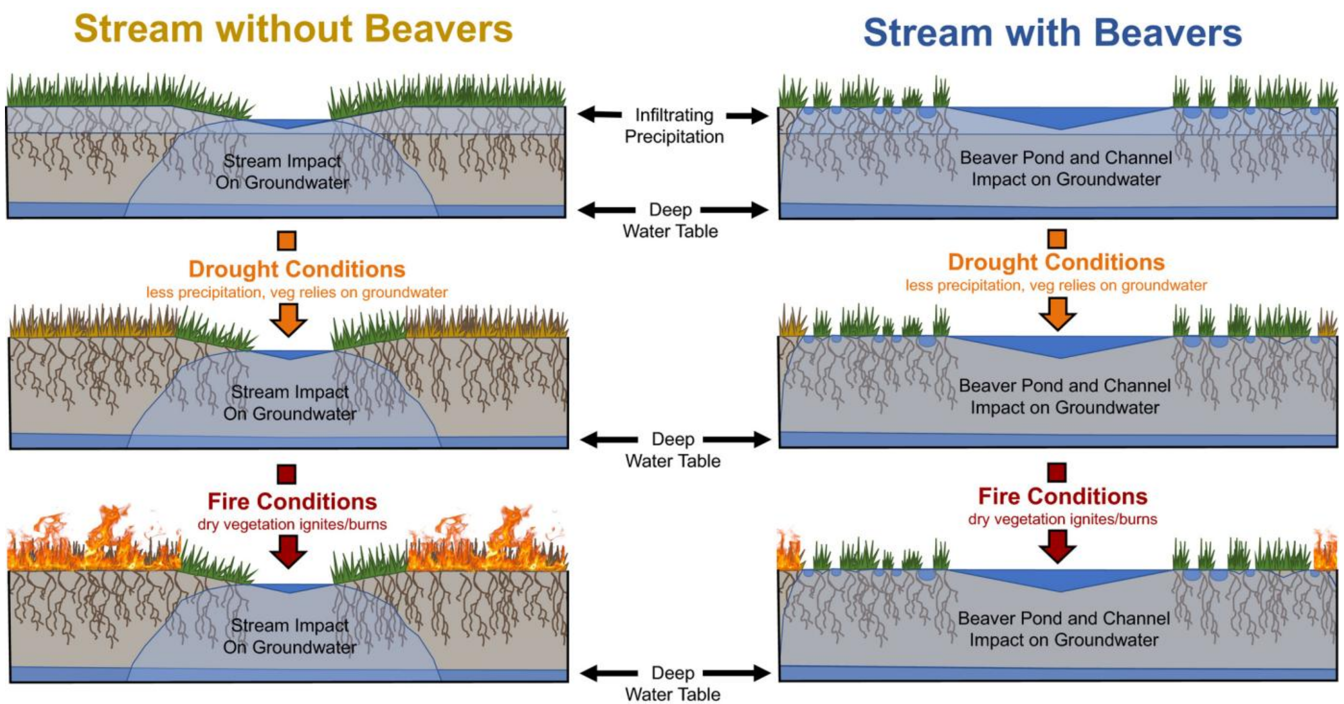
Reduces fire effects by increasing soil and vegetation moisture while also storing carbon and nitrogen in soils (Fairfax et al. 2024, Fairfax and Whittle 2020; Nichols et al. 2012; Norman et al. 2016; Robinne et al. 2021; Silverman et al. 2019).

Application: In one account, when small stone structures were installed to help stabilize a wetland by eliminating incisions that would drain it, the wetland's renewed function was described as "similar to a subsurface irrigation system" (Fairfax and Small 2018) that primed the system for recovery and then maintained it over time.

RESEARCH WEBINAR: Benefits of beaver dams & analogs

Figure shows how beaver dams increase resilience to drought and fire. Across the West, beaver dam analogs are being constructed in watersheds. Click the link above to learn more about the research.

Figure credit: Fairfax and Whittle 2020.



Benefits of natural infrastructure

In addition, there are also many documented increases in species richness, composition, and heterogeneous habitat features associated with the installation of natural infrastructure that can **harbor species during and after fire**—especially compelling results when we consider typical fire/flood patterns in the southwestern U.S. (Norman 2022a).

Collaboration and information-sharing are key. Vital to the efforts today are the many scientists with Army Corps of Engineers, Bureau of Reclamation, U.S. Geological Survey and other major agencies who actively engage with restoration practitioners in the fields, offices, roadsides and other sites where proactive, artful applications of the science that they all create together can contribute to the creation of new and highly informative partnerships as well as projects (Norman et al. 2021; 2022b). As such, pioneering restoration practitioner Bill Zeedyk published his key synthesis of restoration methods which included the words "an evolving method" in its title (Zeedyk and Clothier 2012). It's a call to action, care, and humility at once (see Guidebook & Resource List on page 32).

WATCH A VIDEO: Research
Learn how 30 years of watershed work impacted a watershed in southeastern Arizona.

WATCH AN ANIMATION: Beaver dams build climate resiliency by slowing water down and storing it in their ponds and the surrounding riparian area. Their wetlands are uniquely resistant to disturbances like droughts and fire!
Video credit: Emily Fairfax.

Benefits of natural infrastructure

Increases soil hydraulic properties and organic-systemic resilience at fundamental levels, by mitigating and reducing peak flow curves and channel down-cutting that increase channel slope and water's erosive force (McGuirre and Youberg 2019).

Application: Ecological infrastructure creates the equivalent of a river's riffles in an otherwise "smooth" landscape surface. Heterogeneity of structure fosters roughness and diversity. A flow's destructive energy is dissipated by each structure repeatedly over a channel's course, while the water is stepped down and allowed to flow through. In the process, flows deposit sediment and organic material, often the first substances to be carried out of a system.

ANIMATION: Benefits of natural infrastructure

Image showing how natural infrastructure can be combined to create resilience against negative impacts of wildland fire across a watershed. Some benefits of these structures are listed in the image. See an animation of this infographic at the link above.

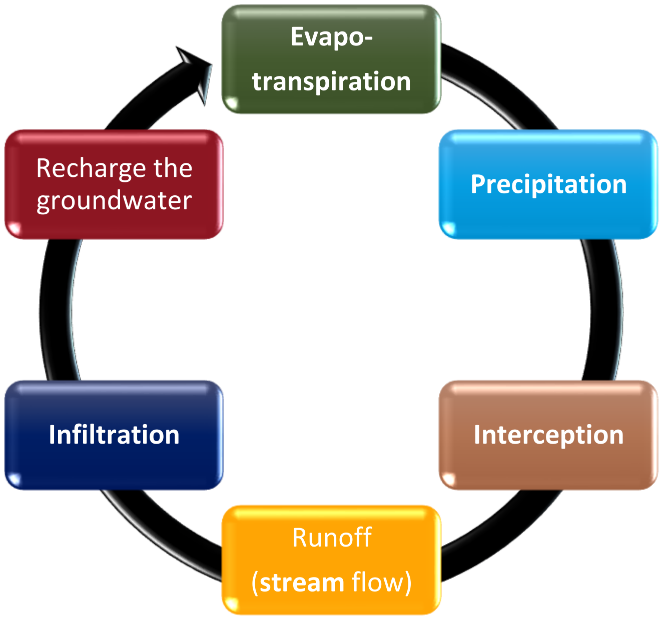
Image credit: US Geological Survey and Heartwood Visuals.

Benefits of natural infrastructure

Increases complexity and resilience for social, ecological and economic benefits through scalability and applicability in all ecosystems (Norman et al. 2021).

Application: The effects of the ecological infrastructure installed and the act of installing it recall the permaculture concept of “stacking functions” all in one system, and one activity. Structural, functional differences are created that become part of the ecosystem, whether a driveway, residential yard, ranch, or national forest. In many cases jobs and training opportunities are created along with habitat in the process; and people are engaged with one another in the vital logic of caring for home. All in all, the practices and approaches represent a unique ethic of care, a contemporary eco-logic needed perhaps as never before in our history.

RESEARCH: Schematic of the hydrologic cycle or water budget used in research of the use of natural infrastructure in dryland systems. When properly and adequately placed, these structures are shown to slow runoff, infiltrate soils support vegetation, and even recharge groundwater supplies. Find out more about the research at the link above. Figure credit: US Geological Survey.



WATCH A TIMELAPSE: Watershed restoration, antelope & water

In Wyoming, watershed work supports both wildlife and livestock grazing by arresting erosion, rebuilding soil, retaining moisture, and supporting the growth of forage in a wetland area. See the full cycle of water harvesting, grazing, and green-up at the link above. Video credit: Wyoming Game & Fish Department.

Benefits of natural infrastructure

Creates economic opportunities in rural places, which can initiate and support markets for these ecosystem services and create foundations of employment and therefore stability and predictability in restoration as a valued profession (Callegary et al. 2021; Gooden and Pritzlaff 2021).

Application: If we can create and sustain powerful wildfire fighting crews, why not "hot-shot" restoration crews, quickly deployable and highly trained in multiple techniques that increase resilience for values of concern, and recovery time in those that have been damaged? Of course, versions of this exist already in tribal modules and conservation corps approaches. Now is the time to support them through systemic infrastructure (compensation, communication, and training systems that they can count on). Support would require being proactive as a means of collectively shaping complex, uncertain, but shared futures, rather than being merely reactive and repeating the management failures of the past.

Many hands make light work. There are many benefits of working together to increase watershed resiliency.
Photo credit: Kate Tirion.

Case studies for research and practice

+ Working across the public-private divide

+ Restoration training across scales and social groups

+ Cross-cultural collaboration towards shared goals

03

Case studies for research and practice

Myriad case studies of natural infrastructure restoration projects, and more importantly partnerships, continue to point to the restorative potentials of collaborative work for both people and places (Norman et al. 2021; 2022b).

Watersheds as laboratories: In one watershed restoration experiment measuring two parallel arroyos—one treated with natural structures and the other left untreated as a control—researchers discovered that rock structures increased subsurface flows, reduced peak flow velocities during storms that cause erosion, and *did not* reduce downstream water availability, a common concern of land managers. In fact, the reality was just the opposite—flow volumes were higher overall in the treated watershed, and water was available over a longer reach of the channel and more predictable over time, increasing the potential for faster post-fire system recovery (Gooden and Pritzlaff 2021; Norman et al. 2016)).

See the high banks in the incised channel on the right? The water continues to erode and down cut, an action that will continue to 'unzip' the landscape as every channel connecting to it will erode to match its elevation. On the left, simple rock structures work to build the banks of the creek back up.
Image credit: Annie Elko and Google Gemini.

Case studies for research and practice

Working across the public-private divide:

In another example, the Babacomari ranch in southeastern Arizona received large-scale stone and wood structure work, including wood posts from a thinning project after a fire on USFS lands *because they share the watershed*, and because fire effects and sediment yield models had already been run by USGS (Norman et al. 2019). In this case, the models and a local non-profit restoration team's flexibility on the ground also enabled a crew to respond immediately to lightning-caused fires on the ranch before subsequent monsoon rains could erode vulnerable soils. All it took was a phone call. The "social infrastructure" had been set up through communication and trust and proof-of-concept work in the vicinity by the non-profit practitioners. Natural infrastructure then needed only to be arranged in place in order to be responsive to local conditions.

Grasslands at Babacomari Ranch.
Photo credit: Molly McCormick.

Case studies for research and practice

Restorative training across scales and social groups: Social and ecological values can be brought together in unique and inspiring ways. In one case, a USFS District Ranger was so enthused by the combination of youth training opportunities in rural communities and scientific proof of improved hydrology and erosion mitigation through natural infrastructure *on public lands*, that he designated funds to support a private, multi-summer youth restoration crew to do the work (Sky Island Restoration Cooperative 2016). Soon after, another local non-profit funded the previous one to train a Department of Corrections prison crew to learn about and build structures in a severely burned watershed. The result was the creation of over 700 sturdy, stone water harvesting features over the course of six weeks, along with a profound sense of accomplishment and pride that the men admitted they had not felt for a very long time.

<u>CASE STUDY</u>: Learn how members of SIRC installed structures after fire in a watershed in the Chiricahua Mountains.

Case studies for research and practice

Cross-cultural collaboration toward shared goals: In terms of fire effects and natural infrastructural responses to them, we can find just as much value in *how* our techniques and approaches combine and inform one another, as we do in *what* technology we choose. In one example of an on-going partnership among USGS, the San Carlos Apache Tribe, non-governmental organizations, and the state of Arizona, the effects of varied climatic events on the San Carlos Apache Reservation are being correlated with riparian vegetation responses over time, and according to San Carlos Apache cultural values around a major water course. Today, adjustments in the management of the riparian corridor are being developed in response to expected future climatic stimuli through high-tech data collection. In the end, this approach will directly inform the types and locations of natural infrastructure applications, including the culturally appropriate time of year to do the work. Riparian vegetation response vs. historical data, tribal insights on historic and desired future conditions, and creative climate adaptation planning are working in tandem to benefit the management of the natural *and* cultural resources of concern at once (Petrakis et al. 2023; emphasis added).

Collaboration in New Mexico in the Rio Grande Watershed

Groups along the Rio Grande River are working to support watershed health by uniting Tribal Youth, restoring wetland jewels in multiple locations, and restoring headwaters.

CAST STUDY: Rio Grande Watershed
PRESENTATIONS: See the work

Carson National Forest in New Mexico has been conducting watershed work.
Photo credit: Carson National Forest.

Case studies for research and practice

VIDEO: The Restoration of Santa Clara Creek

Santa Clara Creek after post-fire restoration.
For an example of collaborative work, see the film, *The Restoration of Santa Clara Canyon*.
Video credit: Erick Gonzalez.

Weaving Indigenous Knowledge and western science to restore a watershed

Throughout the Southwest and in fact worldwide, we find natural infrastructure still actively and literally holding ground today, just as it did when it was installed many hundreds of years ago (Doolittle et al. 1993; Hack 1942; Pandey et al. 2003; Pailes et al. 2023; Woodbury 1960). Indigenous practitioners continue to demonstrate very effectively that tending culturally significant sites and species, for example, is as much about building the capacity of ecosystems to buffer disturbance, shock, and change, as it is about building the capacity of communities to create and maintain adaptive capacity. For many Indigenous communities that continue to model such multi-faceted, restorative approaches, this must include pathways for knowledge transference and shared stewardship, especially in the face of unknowns (Adams 2023; Kimmerer 2013, 2000; Lake and Christiansen 2019; Lake et al. 2017; Long et al. 2020; Pyne 2014, 2015; Stockdale et al. 2019).

Considerations & resources

+ *Bridging currents and futures, economies and ecologies*
+ *What stands in the way?*
+ *Natural infrastructure guidebooks and resources list*
+ *References*

04

Considerations & resources

Successful application of natural infrastructure is participatory, open-ended, and always looking to engage in creative learning opportunities through both patience and persistence—but with a clear-eyed recognition that no single tool is best for all applications. Restoration in this formulation deserves consideration as “practice” rather than product—adaptive to change and never complete, while always benefitting from the further honing of techniques and approaches through communication and shared responsibility. Past approaches to managing landscapes, such as aggressive fire suppression or the draining of wetlands and waterways for development, continue to have impacts, including upon their cultural contexts, that we risk repeating if they are not understood (Berkes 2000; Cook and Reeves 1976; Dobyns 1981; Heede 1960; Nichols et al. 2017).

WATCH A WEBINAR

Engineering With Nature supports wildfire recovery efforts at the Santa Clara Pueblo in New Mexico, emphasizing the development of protocols and design information for Natural and Nature-based Features. These efforts, driven by requests from US Army Corps of Engineers (USACE) Districts and project sponsors, aim to create more sustainable and resilient designs, thereby preparing communities for future wildfire events.

Further Considerations & Resources

Bridging currents and futures, economies and ecologies

Much more needs to be accomplished, and at a faster pace. To be most effective and responsive in the face of current threats, restorative work needs to be valued as a common, fundamental way of "doing business" within existing economies. In the business of restorative work, whether for-profit or non-profit driven, practitioners today know well that funders, managers and landowners all appreciate what Zeedyk (2012) and his trainees call low-cost, low-risk, low-tech work that also results in a demonstrable bang-for-the-buck. It's not too much to ask, and today, the data and the vital reasons for restoration and pre-restoration are right at hand.

In many cases, their **successful proposals for work include**:

- training components for local groups and youth;
- complex, heterogeneous and nimble networks of organizations and abilities;
- inclusion of marginalized groups, solid scientific research, and monitoring; and
- involving local landowners and managers, many of whom are more than ready to cross physical and even their own conceptual and geopolitical boundaries to get the necessary work done.

These are the folks who are ready not only to connect the dots, but to create them; and they're doing that work in agency meetings and kitchens, in boardrooms and bars, and in trucks and on roadsides in progressive and successful ways that deserve notice, both for their social and ecological contributions. We need such inputs, such sources of inspiration and action, like never before. Today, all indications are that we can creatively provision ourselves and our ecosystems with ancient combinations of earth, stone, wood, and fire; and in doing so create unique, contemporary opportunities to be mutually restorative of ourselves and the places we depend upon for survival.

RENT A MOVIE: Beaver Believers

The Beaver Believers is an award-winning feature documentary sharing the urgent yet whimsical story of an unlikely cadre of activists - five scientists and a sassy, spicy hairdresser - who share a common vision. They're all working to restore the North American Beaver, that most industrious, ingenious, bucktoothed engineer, to the watersheds of the American West.
Video credit: BeaverBelievers.com

Considerations & resources

What stands in the way?

While experience with post-fire flooding and watershed recovery tools is increasingly common, there is a critical need to explore proactive measures in fire-prone areas before the flames ignite. Post-fire mitigation is not only expensive, but watersheds may never fully recover. By emphasizing foresight, planning, and leveraging decision support tools, land managers can proactively strengthen watersheds against future wildfire risks.

Yet, a significant knowledge gap exists regarding actionable steps and potential barriers for preemptive measures to reduce the severity of post-fire floods and preserve watershed function.

The Shultz Fire (2010) resulted in multiple flooding events in Coconino National Forest. Photo shows a flooded Forest Service Road. This image was taken three years after the fire.
Photo credit: Kaibab National Forest.

Considerations & resources

What stands in the way?

In a series of listening sessions hosted by the Southwest Fire Science Consortium in 2024, natural resource professionals, students, and researchers were asked about perceived barriers associated with watershed resilience initiatives and solutions that could address them.

Reactive vs pro-active: Watershed work is often reactive and done in the post-fire environment. There are barriers to working in watersheds that are prone to severe wildfire and programs such as Burn Area Emergency Response (BAER) and Burn Area Rehab (BAR) funds streamline the process after the wildfire. Research has shown that watershed work not only reduces wildfire risk but is also cheaper.

+POTENTIAL SOLUTION: Get creative with framing the importance of watershed resilience and create partnerships to do the work.

Cross-jurisdictional challenges: There are many questions around who should conduct planning efforts, pay for, implement, and oversee the work across a watershed.

+POTENTIAL SOLUTION: Ongoing collaborative relationships and organized coordination can help groups make progress on planning and implementation.

Obtaining and training a skilled workforce: Few people are skilled in the craft of watershed restoration, and this can limit implementation of the techniques at watershed scale.

+POTENTIAL SOLUTION: Focusing on training and retention in grant proposals not only looks good to funders but can also sustain the work in the long-term.

Design challenges: With increasing precipitation changes due to climate change, large 500-year floods are increasingly common, making it challenging to know how to design structures.

+ POTENTIAL SOLUTION: Modeling and risk assessment exercises can elucidate where to start the work.

Natural infrastructure guidebooks and resources list

Selected restoration field guides that demonstrate and deploy ecosystem science research in the field, and a willingness to experiment and learn at once (see also References section, and websites of ecological restoration and collaborative conservation groups).

"Post-Wildfire Recovery through the Principles of Engineering with Nature"	Chris Herring, Army Corps of Engineers See: youtube.com, "Engineering with Nature" podcast	Program aligns natural and engineering processes at all scales for social, economic and ecological benefits
"Field Guide on Using Pinon-Juniper Materials in Erosion Control Structures" (2022) and *"An Introduction to Erosion Control" (2006) with Zeedyk*	Jansens: Ecotone Landscape Planning LLC See: ecotonelandscapeplanning.com (English and Spanish)	Brush generated from forest thinning projects can be repurposed for erosion control, mulch, reduced surface temperatures
"Erosion Control Field Guide" *(English and Spanish)*	Sponholtz and Anderson (2010): Quivira Coalition See: quiviracoalition.org	Rock structure types, applications, techniques
"A field guide for the assessment of erosion, sediment transport, and deposition in incised channels of the southwestern U.S."	U.S. Geological Survey Prepared in cooperation with the Bureau of Indian Affairs By: John T.C. Parker https://doi.org/10.3133/wri994227 Water-Resources Investigations Report 99-4227	Extensive review of erosion causes, definitions of terms and examples of challenges in the Southwest with sources for further research
"A Good Road Lies Easy on the Land…Water Harvesting from Low-Standard Rural Roads"	Zeedyk (2006): Quivira Coalition See: quiviracoalition.org	Road design techniques to reduce erosion, for maintenance, and to direct water to beneficial areas
"An Introduction to Induced Meandering: A Method for Restoring Stability to Incised Stream Channels"	Zeedyk (2006): Quivira Coalition See: quiviracoalition.org	Creative methods for using a channel's hydraulics to slow erosion and improve function
"Let the Water Do the Work: An Evolving Method for Restoring Incised Channels"	Zeedyk and Clothier (2012): Quivira Coalition See: quiviracoalition.org	Ties hydrology, ecology and geomorphology together to heal ecosystems

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Link Library

*Listed in order of appearance

Case studies

- GIS StoryMap: Post-fire flooding: The Museum Fire, https://storymaps.arcgis.com/stories/44d0611ff906462890798b87b69c017e
- Resources: Coconino County Flood Control District, https://www.coconino.az.gov/2926/SchultzPipeline-Flood-Area
- Video: Zeedyk structure timelapse, https://www.youtube.com/watch?v=cfobSpapImA
- Fact sheet: Post-fire watershed restoration and monitoring in the Chiricahua Mountains of Arizona, https://www.swfireconsortium.org/wp-content/uploads/2024/09/Post-Fire-Watershed-Restoration-and-Monitoring-in-the-Chiricahua-Mountains-of-Arizona.pdf
- Website: Stories in New Mexico on Rio Grande watershed restoration, https://www.nature.org/en-us/about-us/where-we-work/united-states/new-mexico/stories-in-new-mexico/restoration-projects-rio-grande-watershed/
- Video: The Restoration of Santa Clara Canyon, https://www.swfireconsortium.org/2024/09/17/santa-clara/
- Documentary movie: The beaver believers, https://ewn.erdc.dren.mil/presentations/wildfire-recovery-using-engineering-with-nature-principles/

Research

- Webinar: Pre- and post-Fire impacts of beaver dams and beaver dam analogs, https://www.swfireconsortium.org/2025/02/21/pre-and-post-fire-impacts-of-leave-dams-and-leave-dam-analogs/
- Video: Can rock dams reverse climate change, Re-greening a dryland watershed, https://www.youtube.com/watch?v=c2tYI7jUdU0
- Video: Beavers and wildfire: A stop-motion story by Emily Fairfax, https://www.youtube.com/watch?v=IAM94B73bzE
- Website: Aridland water harvesting study, https://www.usgs.gov/centers/western-geographic-science-center/science/aridland-water-harvesting-study

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Guides & Training Resources

- Book: Low-tech process based restoration of riverscapes design manual, https://lowtechpbr.restoration.usu.edu/manual
- Video: An afternoon with Van Clothier, Grassland restoration methods, https://www.youtube.com/watch?v=NCu6xia9zKg&t=453s
- Video: Why do rivers curve?, https://www.youtube.com/watch?v=8a3r-cG8Wic&t=3s
- Video: Nature based structures for watershed restoration, https://www.youtube.com/watch?v=VUDlitH2uhI&t=76s
- Video: Aridland water harvesting study animation, https://www.youtube.com/watch?v=gE2xqiIei9g
- Video: Wildfire recovery using engineering with nature principles, https://ewn.erdc.dren.mil/presentations/wildfire-recovery-using-engineering-with-nature-principles/