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The Application of Engineering With Nature® Principles in Colorado Flood Recovery

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PURPOSE: This technical note features river-based restoration projects that incorporate Engineering with Nature® (EWN®), Natural and Nature Based Features (NNBF) approaches in the Front Range of Colorado as part of a comprehensive flood recovery program to protect life and property.

INTRODUCTION: In early September 2013, several days of rain caused severe flooding across the Colorado Front Range. The streams and rivers throughout this region reclaimed floodplains, destroyed roads, bridges, buildings, and existing riverbank vegetation (Figure 1) (CWCB 2018). The flood resulted in approximately $4 billion in damage to infrastructure on both public and private property (CWCB 2018). As part of the Phase I recovery efforts, emergency repairs were completed by state and federal agencies that included clearing debris from river channels and bridge span to re-open roads and highways. However, the initial recovery efforts often caused additional damage to river systems through the placement of stop-gap riprap, short-term bank stabilization and removal of large woody materials, often leaving improper stream channel alignment and insufficient flood capacity and conveyance (CWCB 2018). Following Phase I emergency stabilization, state, federal, and local governments along with private companies, non-profit organizations, and committed citizens came together to design and implement the Colorado Flood Recovery Program (CFRP).

Figure 1. Damage from September 2013 floods.

As part of Phase II flood recovery, the CFRP sought to take a new, more holistic approach to address hazards to life and property and restore the health and function of stream corridors impaired by the disaster and Phase I emergency stabilization repairs (CWCB 2018). The Phase II Program used EWN and traditional engineering approaches to incorporate resilient designs to assist in developing and implementing holistic mitigation strategies to limit damage during future flood events. Integration of traditional engineering approaches with EWN provides designs that are more sustainable in dynamic fluvial systems.

The CFRP, managed by Colorado Department of Natural Resources – Colorado Water Conservation Board (CWCB), provides various funding mechanisms through federal and state recovery programs, including the Emergency Watershed Protection (EWP) Program through the USDA Natural Resources Conservation Service (NRCS), CWCB, Colorado Senate Bill 14-179, and Community Development Block Grant (CDBG)- Disaster Recovery Grants, administered by the Colorado Department of Local Affairs (DOLA) and funded through the US Department of Housing and Urban Development. Of the $68.3 million in funding for EWP, the NRCS contributed 75%, CWCB contributed 12.5% and managed the program, and local partnerships including the Watershed Coalitions provided 12.5% as match. For the CDBG Grants, DOLA providing $4.6 million, and for the Colorado Senate Bill 14-179 projects, CWCB provided $2.53 million. In addition to these programs, numerous other partners provided watershed and flood recovery support and developed flexibility in funding requirements to collaborate with the CFRP.

The primary goals of CFRP were to (1) implement a watershed-based flood recovery approach that reduced the risk to life and property, (2) use federal and state funds effectively, (3) enhance the health and resiliency of stream corridors and watersheds, (4) build capacity of watershed coalitions, and (5) advance a watershed-based flood recovery (CWCB 2018). The approach began with the formation of eight watershed coalitions, financial support of two existing watershed coalitions, and the development of watershed-based master plans within the affected regions. These plans, coordinated by the watershed coalitions, were utilized to guide communities through project prioritization in a manner that considered the overarching goals, while integrating hazard mitigation and risk reduction strategies in a holistic manner by watershed. These master plans were inclusive and involved diverse interests including private landowners and residents, governments, and nonprofit organizations (CWCB 2018).

Once complete, the watershed coalitions identified the highest-priority projects within the master plans. These projects (or project areas) were considered under the NRCS EWP Phase II program. To further select projects and obtain emergency funds from the NRCS EWP Phase II program, the NRCS Damage Survey Team completed Damage Survey Reports (DSR). DSRs document damage, estimate treatment methods and costs, identify assets at risk, note environmental concerns, identify project boundaries, and assist in determining a benefit-cost ratio of the proposed treatment (NRCS 2020). Technical teams that included CWCB, coalition representatives, and sponsors provided input to the DSR process in determining project eligibility. Once the DSR process was completed, the NRCS selected projects based on prioritized criteria including funding, uplift potential, agency and local support, and derived benefit. All selected projects were included within the CFRP.

Those projects prioritized within the CFRP went through a design-build process with diverse design and implementation teams that included expertise in permitting, engineering, fluvial geomorphology, fisheries biology, ecology, botany, etc. The watershed-based design approach is the guiding principle for accommodating natural geomorphic processes in restoration designs to enhance long term river function (CWCB 2020). This approach planned for sediment depositional zones, mimicking natural processes, as well as incorporated natural materials for bank stabilization and floodplain roughness. Natural materials consisted of site-specific native plants installed and seeded by hydrologic zone, as well as in situ materials such as boulders and rocks to assist with grade control as well as provide habitat and refugia for aquatic organisms. Also, where possible, project design included space for future channel migration (CWCB 2020). From the onset, conceptual designs were created on an entire watershed basis so that physical and ecological concerns were addressed throughout the design and implementation process (CWCB 2020). This watershed design approach sought to accomplish the following:

- Provide for temporary water storage and reduce peak flood flows for adjacent and downstream communities
- Improve and protect water quality
- Provide diverse, dynamic, and uplifted habitat complexity to biotic needs for resident species
- Reduce reliance on channelization, levees, and bank armoring, which are often detrimental to stream health, expensive to maintain and have proven to be prone to failure
- Increase recreational opportunities for wildlife viewing, fishing, hunting, foraging, and enhancement of trail systems
- Provide natural fire breaks
- Provide space for erosion and sediment deposition during flood and/or wildfire (CWCB 2020).

Recognizing the resiliency and co-benefits offered by EWN, the CFRP combined EWN approaches through the integration of NNBF and stakeholder engagement across the project sites. NNBFs are landscape features that are used to provide more sustainable engineering functions relevant to flood risk management, while producing additional economic, environmental, and/or social benefits (Bridges et al. 2015). NNBFs were incorporated into the watershed-design approach and consisted of riverine bioengineering techniques, natural grade control, remeandering, floodplain reconnection, oxbow reconnection, and the use of native site-specific vegetation through strategic plantings applied by hydrologic zone to increase the ability of the riparian zone to flex and co-evolve with natural processes.

THE EWN APPROACH: EWN is a US Army Corps of Engineers initiative that began in 2010 to highlight existing examples of NNBF while advancing current and future capabilities. The initiative supports more sustainable practices, projects, and outcomes by aligning natural and traditional engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes (Figure 2) (Bridges et al. 2014; Gerhardt-Smith and Banks 2014).

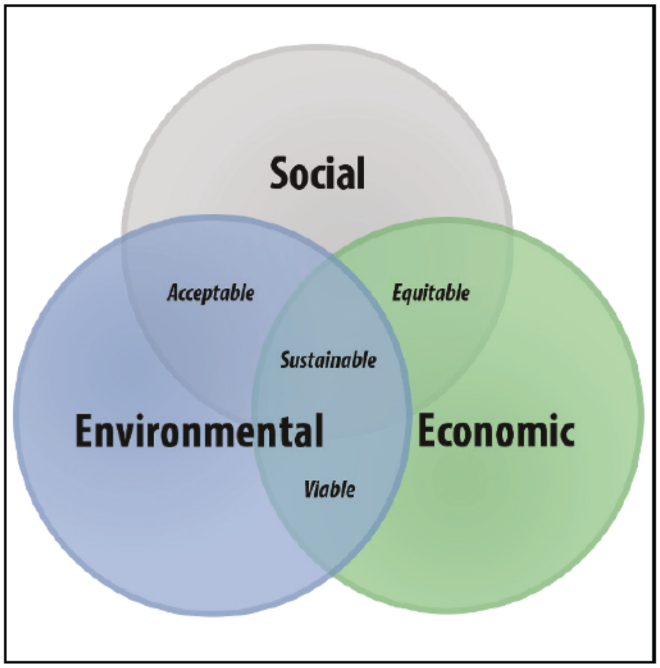


Figure 2. EWN core elements.

The EWN initiative supports more sustainable water resource practices, projects, and outcomes by pursuing the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaboration (*www.engineeringwithnature.org*). A key aspect of EWN is science-based collaboration to organize and focus interests, stakeholders, and partners to produce more broadly acceptable projects. Specifically, there are four critical elements that define the EWN approach:

Producing Efficiencies: Using science and engineering to produce operational efficiencies

Using Natural Processes: Using natural processes to maximize benefit

Broadening Benefits: Increasing the value provided by projects to include social, environmental, and economic benefits

Promoting collaboration: Using Collaborative processes to organize, engage, and focus interests, stakeholders, and partners

APPLICATIONS OF EWN WITHIN THE COLORADO FLOOD RECOVERY PROGRAM: Presented herein are examples of EWN elements and NNBF that were incorporated into the CFRP. Each of these elements demonstrates the added economic, environmental, and social benefits that can be achieved from forward thinking, innovative planning, the integration of NNBF, and collaboration to maximize the success of flood recovery projects.

Collaboration and Stakeholder Engagement. Essential to CFRP was collaboration and stakeholder engagement, involving communication, stakeholders, and training. Communication focused on the development of explicit goals and objectives for recovery and clear communication of these goals through the recovery process. (CWCB 2020). It also focused on the creation and empowerment of local groups, coalitions, and governments to work cohesively on a watershed basis through strong and effective partnerships (CWCB 2020). Accordingly, watershed coalitions were created and funded for each of the flood affected watersheds. The purpose of a watershed coalition is to promote stewardship of issues that affect watershed health as well as serve to assist the planning, implementation, and monitoring for restoration projects occurring within a given watershed (CWCB 2018).

Watershed coalitions implemented stakeholder engagement in several ways. First, they worked cooperatively with federal and state agencies, local municipalities, vested parties and businesses, and local landowners to create Master and Recovery Plans and select prioritized projects. Second, they facilitated public meetings to help ensure local buy-in and alignment of priorities (Figure 3). Third, they worked directly with landowners to address questions and concerns, keep landowners and various stakeholders informed on project status, and obtain project permissions. Fourth, they were the interface between the watershed stakeholders and the design team, to ensure that the final restoration designs were in alignment with local landowners and stakeholders. Fifth, through grants they are continuing to engage with landowners to monitor and maintain project sites to ensure long-term success and resiliency.

Figure 3. Watershed recovery planning at the Saint Vrain River in Boulder.

Floodplain Connectivity. As the interface between a riverine system and its surrounding landscape, floodplains play an integral role for the maintenance of riverine and watershed health (Trout Unlimited 2020; Opperman et al. 2010; Ickes et al. 2005). Functional floodplains are dynamic, and when properly connected through periodic inundation, floodplains provide ecological services such as flood attenuation, dissipate energy, hydrology, and hydraulics by serving as *release valves* during high-flow flooding events. They improve and sustain provision of water quality, moderate stream temperatures, sequester carbon, increase biodiversity and biotic productivity, and enhance wildlife habitat, forage (e.g., reinvigoration of food webs), and refugia (American Rivers 2020; Opperman et al. 2010; Ickes et al. 2005). There are five key components to a connected floodplain: (1) longitudinal – linear connectivity along the entire length of the riverine system; (2) lateral hydrologic connectivity between the river/stream and the floodplain; (3) vertical – hyporheic connectivity from below the streambed and its supporting aquafers to the active channel to the atmosphere; (4) variable flow regimes ranging from periods of flooding/high flow to lower flow conditions; and (5) sufficient scale for key processes and benefits to occur (MDNR 2020; Opperman et al. 2010; AFPM 2006; Ickes et al. 2005). The interaction between these five components creates complex, interdependent processes that vary over time. While these components are known to be key to a healthy and functioning floodplain, floodplains are considered to be one of the most imperiled portions of riverine systems due to their disconnection from riverine systems. This is most commonly referred to as "altered lateral connectivity" (Opperman et al. 2010; Ickes et al. 2005).

Central to the CFRP success with floodplain connectivity was its understanding that rivers, streams, and wetlands are intrinsically interconnected systems (CWCB 2018). Rivers and streams are dynamic systems that naturally move within a given riverine corridor, thereby adapting through the deposition and transport of water, debris, and sediment (CWCB 2020; Giordanengo et al. 2016). Understanding that fluvial systems are interconnected hydrologically and hydrodynamically with their supporting wetlands served as a core tenant for the CFRP (CWCB 2018). Within the CFRP, floodplain connectivity was facilitated through (1) encouraging longitudinal connectivity through riffle pool sequences to dissipate stream energy; (2) promoting lateral hydrologic connectivity through the removal of flood-deposited sediment and the creation floodplain benches and overflow channels; (3) incorporating proper hydrology and hydraulics for low flows, annual flows, and flood events into channel designs; and (4) removing invasive species that altered hydrology and resulted in blockages during the 2013 flood events (e.g., crack willow [*Salix fragilis*]).

Using Natural Processes

The concept of floodplain connectivity inherently incorporates natural processes. Connected floodplains, overflow channels, and oxbows serve to further dissipate energy and naturalize hydrology and hydraulics, in essence serving as *release valves* during high-flow flooding events (Wohl et al. 2016; Dickard et al. 2015; AFPM 2006; Singh et al. 2003a; Singh et al. 2003b). Such energy dissipation is further assisted through understanding fluvial geomorphology principles of restoration sites, revegetation according to hydrology, and increased channel roughness through the correct application and orientation of large woody materials and biostabilization (Wohl et al. 2016; Opperman et al. 2010; Ickes et al. 2005). Recognizing the importance of geomorphic complexity and associated benefits on hydrology and hydraulics, for each of its projects, the CFRP prioritized the reconnection of floodplains to increase in hydrologic infiltration and retention times, facilitate flood flow storage, spread and energy attenuation across the floodplain, and the return of riverine connectivity to its surrounding environment (CWCB 2018).

Streambank Bioengineering Applications. Streambank bioengineering relies on natural processes that combine structural, biological, and ecological principles to construct living structures for slope stabilization, reduced soil erosion, revegetation, and flood control (USDA NRCS 2018; Giordanengo et al. 2016; Hoag and Fripp 2005; Eubanks and Meadows 2002). Streambank bioengineering is divided into two general approaches: plant-based bioengineering and structural-based bioengineering (USDA NRCS 2018; Giordanengo et al. 2016). These approaches are divided based on intended function, material type, and ability to dynamically change over time and are both examples of NNBF (USDA NRCS 2018; Giordanengo et al. 2016). As the name suggests, plant-based bioengineering uses riparian plants to provide long-term bank stability and strength by using root systems to bind soil particles and impart cohesion to the soil and resistance to erosional loss (Giordanengo et al. 2016). This type of treatment is flexible and dynamic and can be used on sites that do not require a static bank line protection where bank erosion is expected during high flows (USDA NRCS 2018; Fripp et al. 2008). Examples of plant-based treatments include live willow clumps, fascines, brush trenches, and live plant materials.

Structural-based bioengineering uses structural materials such as native in-situ rocks, riprap, logs, manufactured products, or inert material for channel stabilization (USDA NRCS 2018). This type of treatment is designed to create quasi-static banks that remain stable under high velocity water flows or constant inundation. This treatment is used on river channels and bank slopes that are exposed to erosive forces and require more than vegetation to provide adequate erosion resistance (USDA NRCS 2018). Additional engineering and structural-based design approaches are required to treat eroding banks that are intended to be static and/or high-risk sites where bank movement is unacceptable (e.g., adjacent to bridges, highways, urban corridors). Structural-based bioengineering can be combined with vegetation such as willow or cottonwood cuttings to impart greater resistance to erosional loss. Examples of structural-based treatments include soil covered riprap, riprap toe and in situ boulder cobble toe protection, vegetated riprap, boulders, joint planting, engineered log jams, rootwad revetments, and many others.

Within the CFRP, streambank bioengineering practices were used to improve flood resiliency, reduce erosion through combination of NNBF and traditional engineering techniques, and holistically restore the health and function of watersheds and stream corridors while also planning for and increasing resiliency toward future flooding events. Inherent in streambank bioengineering is the use of plant materials such as cuttings, rooted stock, transplanted stock, and seeding to stabilize soil and reduce erosion (Giordanengo et al. 2016; Hoag and Fripp 2005; Eubanks and Meadows 2002); however, not all streambank bioengineering implemented within the CFRP included plant materials. When selecting a structural versus plant-based bioengineering versus traditional engineering treatment, the CFRP considered a diversity of treatment options based on the desired outcomes. Each treatment was considered in the context of the entire floodplain rather than based on individual treatments. Because streambank bioengineering treatments are not designed to withstand the same magnitude design conditions as traditional engineering treatments, the streambank bioengineering treatments were considered on a case-by-case basis. If greater stability was required, then a traditional treatment was relied upon. Bioengineering treatments were applied where there was a high probability of providing the desired function for the system.

For example, in areas with low erosive forces that did not require asset protection, a plant-based treatment was considered; in areas that require moderate bank stability, and a static bank is required for asset protection, a structural-based treatment was considered; and in areas that require substantial asset protection such as protection of houses or bridges, traditional engineering techniques were considered. A table identifying streambank engineering techniques applied throughout the CFRP and its associated applications can be found in Table 1. The streambank engineering techniques applied within the CFRP align with the EWN elements by producing efficiencies, using natural processes, broadening benefit, and promoting collaboration.

Producing Efficiencies

Living (biotic) and non-living (abiotic) material found on site can be used to construct streambank bioengineering techniques. The immediate proximity and availability of these resources reduces time and associated cost of construction by not having to move materials to or from the project site. In addition, access to haul materials into a site is limited; therefore, using in situ materials is not only cost effective but also is more practical. Within the CFRP, flood-damaged cottonwoods and conifers were used to construct rootwad revetments. In addition, wherever possible, existing natural rocks and gravels were used for grade control, bank stabilization, pool creation, and boulder-cobble toe features throughout the site.

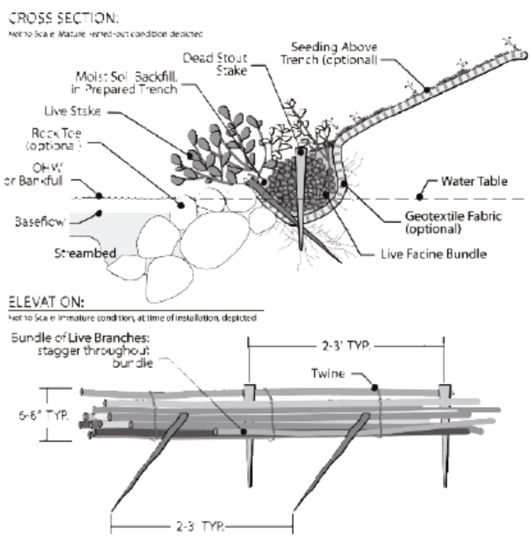
Using Natural Processes

Streambank bioengineering incorporates living materials inherently uses natural processes to stabilize banks and increase erosional resistance. Roots of the living materials bind the soil matrix through cohesion while also providing habitat for insects, microbes, and animals (Giordanengo et al. 2016). Vegetation with dense, fibrous root systems reinforce the soil matrix through the transference of shear stress within the soil to tensile strength inherent within the root structure (Giordanengo et al. 2016; Simon et al. 2006). Above-ground vegetation also armors and stabilizes the soil surface, reduces erosion through canopy interception, and provides surface roughness to reduce overall shear stress across a site (Giordanengo et al. 2016). The CWRP incorporated riparian vegetation with dense, fibrous root systems into each project to stabilize banks and increase erosional resistance across the site.

Table 1. Streambank bioengineering techniques and their associated applications incorporated in the CFRP.

Techniques Implemented throughout Colorado Program	Bioengineering Type	Benefits (*) and Applications (+)	Projects Implemented
Brush Trench 	Plant-based bioengineering	• Captures sediment and flood debris during flood conditions (*, +) • Filters runoff before entering the stream (*, +) • Enhances conditions for colonization of native vegetation (*) • Restores riparian vegetation and streamside habitat rapidly (*, +) • Provides biological habitat (*) • Effective on floodplain benches of all scales (+)	Streamcrest and Ranch North Fork of the Big Thompson SSV3 Big Thompson Projects Stagecoach
Vegetated Soil Lifts/Soil Wraps 	Plant-based bioengineering	• Aids in natural regeneration colonization (*) • Provides immediate protective cover for the bank (*, +) • Provides rapid reestablishment of riparian vegetation (*) • Reduces surface erosion (*, +) • Reduces toe erosion (*, +) • Decreases flow velocities and shear stresses along the bank during high water stages (*, +) • Used where the bank cannot be re-graded to a shallower slope (+)	Bielins Hock Moodie

Vegetated Riprap/Joint Planting 	Combination of plant-based and structural bioengineering	• Aids in natural regeneration colonization (*) • Minimal site disturbance (*,+) • Protects banks from shallow slides and stabilizes banks (*, +) • Dissipates flow energy and traps sediment (*, +) • Branches add tensile strength to bank (+) • Combination of boulder cobble toe with joint plantings provides added tensile strength and toe protection. (+) • Boulder cobble toe stabilizes toe of bank providing protection while vegetation stabilizes mid and upper (*, +) • Joint plantings deflect overbank high flows when planted close together (*, +)	South St. Vrain Projects Coal Creek Projects Big Thompson Projects Four Mile Projects Left Hand Creek Projects
Live Post/Stake and Rooted Stock 	Plant-based bioengineering	• Branches add tensile strength to mid and upper banks (*, +) • Deflects strong or high flows when planted close together (*, +) • Aids in natural regeneration colonization (*) • Reduces wind and water velocities hitting mid and upper banks (*, +) • Roots stabilize mid and upper banks (*)	All Projects

Fascines 	Plant-based bioengineering	• Stabilizes toe of bank providing protection to wetland and riparian vegetative plantings (*, +) • Aids in natural regeneration colonization (*) • Roots stabilize mid and upper banks (*) • Could be paired with a riprap or boulder cobble toe to provide toe stabilization (+) • Provide both erosion control and structural functions, both individually and as constituents of more complex treatments (+) • Dissipates flow energy and traps sediment (*, +) • Reduces toe erosion when paired with riprap or boulder cobble toe protection (*, +) • Maintains a natural bank appearance (*) • Protects banks from shallow slides (*, +)	Fish Creek North Fork of the Big Thompson Hall Ranch
Boulder or riprap toe with Large woody debris/ material/ Root Wad Revetment	Combination of plant-based and structural bioengineering	• Stabilizes toe of bank providing protection to wetland and riparian vegetative plantings (*, +) • Aids in natural regeneration colonization (*) • Appropriate above and below OHW/bankfull (+) • Filter barrier to prevent erosion and scouring of the bank (*, +)	Left Hand Creek Projects South St. Vrain Projects Middle South Platte Breaches Little Thompson Projects

		• Maintains a natural bank appearance (*) • In combination with vegetative plantings, provides rapid reestablishment of riparian vegetation (+) • Reduces erosion to toe of the bank (*) • Dissipates flow energy and traps sediment (*, +) • Willow cuttings can be used to add tensile strength to bank (+) • Provides aquatic habitat (*)	
Boulder-cobble toe 	Structural-based bioengineering that could be paired with a plant-based bioengineering treatment.	• Stabilizes toe of bank providing protection to middle and upper bank vegetative plantings (*, +) • Stabilizes banks on high risk sites where bank movement is unacceptable (*, +) • Appropriate below OHW/bankfull (+) • Reduces erosion to toe of the bank (*) • Willow cuttings can be used to add tensile strength to bank (+) • Traps sediment (*, +)	Streamcrest and Ranch North Fork of the Big Thompson SSV3 Big Thompson Projects Left Hand Creek Projects

Natural grade control 	Structural-based bioengineering	• Stabilizes toe of bank providing protection to middle and upper bank vegetative plantings (*, +) • Stabilizes banks on high risk sites where bank movement is unacceptable (*, +) • Appropriate below OHW/bankfull (+) • Willow cuttings and fascines can be used to add tensile strength to bank (+) • Aids in natural regeneration colonization (*) • Effective in steep rocky canyons (+) • Can be designed to reconnect floodplains (+)	Big Thompson Projects North Fork of the Big Thompson

PROGRAM OUTCOMES AND PREPARING FOR THE NEXT FLOOD: There are several enduring outcomes of the CFRP. After 5 years, the CFRP successfully implemented 117 flood mitigation and restoration projects including 65 miles of river and floodplain improvements over nine watersheds in the Front Range of Colorado (CWCB 2018). These restoration projects have directly provided ecosystem services to local communities including improved ecology, health, safety, recreation, quality of life, protection of homes, flood protection, and hazard reduction.

Broadening Benefits

The CFRP 65 miles of restored river and floodplain provided a range of environmental, social, and economic benefits to Colorado including the following:

- Flood protection and increased resiliency to future flood events
- Sediment reduction and water quality improvements
- Community engagement and awareness surrounding watershed-scale planning and management
- Recreational opportunities for wildlife viewing, fishing, hunting, and foraging
- Aesthetic and spiritual enjoyment.

Restoration Matrix. A second outcome of the CFRP is the development of an interactive river restoration matrix that was developed to help inform project designers and implementors on past and future river restoration work throughout Colorado. The interactive restoration matrix assisted designers in effectively selecting appropriate plant materials for use in revegetation and bioengineering structures based on key characteristics for approximately 280 ecotypic plant species.

Key Characteristics include:

- Taxonomy
- Hydrologic zonation and tolerance
- Root morphology and structural strength
- Country occurrence
- Elevation and aspect
- Successional stage
- Shade tolerance
- Life form (grass, graminoid, forb, shrub, or tree)
- Wildlife benefits
- Adaptability to soil chemistry and texture
- Collection and propagation
- Likelihood of survival
- Site specificity and endemism
- Frequency of occurrence
- Wetland regulatory status
- Wildlife and livestock toxicities

While the matrix was designed for use in the CFRP, the matrix is publicly available through CWCB and can be used to guide restoration and stabilization projects throughout the state of Colorado. (*https://www.coloradoewp.com/design-and-permitting*).

Colorado Disaster Recovery Lessons Learned. A third outcome of the CFRP was the development of a Colorado Disaster Recovery Lessons Learned guidance document. As with other large and innovative programs, there were lessons that were learned throughout the process. Using input from project sponsors, design teams, and a series of in-person interviews, the State of Colorado developed a Lessons Learned guidance document to provide flood recovery managers with guiding principles and actions to achieve the best possible outcomes following disaster events. The document introduces flood recovery managers to a series of environmental, social, and economic considerations following a disaster and focuses on recommendations for the following: (1) improvement of existing state and federal disaster responses; (2) Disaster Recovery Actions; and (3) Pre-Disaster Actions.

Colorado Hazard Mapping Program. A fourth outcome of the CFRP was the development of the Colorado Hazard Mapping Program, which was composed of the Flood Hazard Mapping Program and Debris Flow Mapping Program for the State of Colorado (CWCB 2018). Following the 2013 floods, it was evident that areas throughout Colorado were not appropriately mapped as hazard areas and could be subject to future flood events. That is because, traditionally, erosion, sedimentation, channel evulsion, debris and mud flows have not been incorporated into floodplain mapping. Therefore, as an offset of the CFRP, CWCB developed fluvial hazard zone (FHZ) and a debris flow (DF) mapping programs that focused on the identification and mapping of FHZs and DFs to better understand the entirety of hazards associated with flooding and rain events (CWCB 2018; DOLA 2018). The FHZ is broadly defined as the areas a stream has occupied in recent history, could occupy, or could physically influence as it stores and transports sediments and debris during flood events (Jagt et al. 2016). The DF program aims to map those areas susceptible to debris flows as well as identify the area that may be inundated with debris following large flooding events. The objective of these programs is to identify lands most vulnerable to fluvial and debris flow hazards in the near term and allow state and local government agencies to develop programs and regulations that limit investments and avoid development within mapped hazard zones (Jagt et al. 2016).

SUMMARY: This document summarizes Colorado Flood Recovery Projects, which successfully applied EWN principles for flood recovery following a devastating flood in 2013. Principles used throughout the program include *stakeholder engagement* to develop local buy-in; focus on *floodplain connectivity* to naturally dissipate flood flow energy, increase retention and infiltration times, and return connectivity to impacted river systems; and *streambank bioengineering* techniques to use natural materials to increase sediment stability and reducing erosion potential through cohesion, natural armoring by biota, and surface protection. This large-scale flood recovery program demonstrates that sustainable practices and outcomes can be achieved in flood recovery when the goals intentionally align natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes. Other states and agencies should consider broadening flood recovery to include EWN principles (or elements) and more effectively manage the nation's waterways.

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