Southern Rockies Landscape Conservation Cooperative Unit Watershed Erosion Potential Prioritization for Check-Dam Installation

Open-File Report 2018–1127

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph of rock check-dam in an intermittent drainage adjacent to the Colorado River on the Palisades Delta in Grand Canyon National Park, Arizona, constructed by the Pueblo of Zuni in 1995. Approximately 30 centimeters of sediment were deposited behind the check-dam. (National Park Service photograph taken March 2005.)

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Abbreviations

BioClim	bioclimatic variables from the WorldClim dataset
CDL	crop data layer
CONUS	contiguous United States
DEM	digital elevation model
EPA	Environmental Protection Agency
GeoWEPP	Geo-spatial interface of the Water Erosion Prediction Project
HUC	hydrologic unit codes
NASS	National Agricultural Statistics Service
NCGC	National Cartographic and Geospatial Center
NRCS	Natural Resources Conservation Service
RUSLE	Revised Universal Soil Loss Equation
SRLCC	Southern Rockies Landscape Conservation Cooperative
gSSURGO	Gridded Soil Survey Geographic database
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WBD	Watershed Boundary Dataset

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Abstract

Changes in land-use practices and the extirpation (local extinction) of beaver populations in the early 20th century during European settlement are believed to have resulted in many changes in how streams in the Western United States function. Some of the negative changes that have resulted include stream channelization, soil erosion, changing vegetation, water turbidity, and a loss of overland flow. Efforts to restore streams and reduce soil erosion by water have included reintroductions of beaver, incorporating Native American traditional knowledge of dry-land farming techniques, and the installation of rigid check-dams. Many of these efforts have been successful in improving both intermittent and perennial stream function. Therefore, stakeholders in the Southern Rockies Landscape Conservation Cooperative (SRLCC) have identified a need to prioritize streams within their region of interest for the installation of check-dams to continue restoration and conservation efforts and to improve sediment catchment.

Using Natural Resource Conservation Service soil databases, topographic features derived from digital elevation models, stream networks, and regional climatic patterns, I developed a ranking system for watershed potential erosion rates and suitability for check-dam placement across the SRLCC. This ranking system serves as a first step for land managers to prioritize areas for check-dam installation based on relatively static factors (soil properties, topography, and hydrology) that can contribute to rates of soil erosion by water and the stability of check-dams. Many other relatively dynamic factors over time can contribute to rates of soil erosion by water, such as recent wildfire events, changes in weather patterns and extreme climate events, and changing land-use such as grazing, logging, mining, development, and cultivation. These factors that influence vegetative and biological soil crusts cover are also important elements to the potential erosion of soil by water. Because of this, SRLCC stakeholders might consider further evaluation of the watersheds identified here as high ranking. Final watershed prioritization among the high-ranking watersheds identified here should include current knowledge of land-use and land-cover estimates to identify areas at risk for soil erosion or degree of existing erosion problems.

Introduction

Erosion, the physical process where soil particles are moved from the ground surface by water or wind (Osterkamp, 2008), can result in lowered soil fertility and increased turbidity of runoff. Water erosion rates depend on many factors including precipitation intensity, soil characteristics, topography of terrain, and the cover of vegetation and biotic soil crusts. The most widely used model to predict soil erosion is the Revised Universal Soil Loss Equation (RUSLE), which consists of five factors—(1) a climatic parameter, the rainfall runoff erosivity factor (*R*), (2) a soil type erodibility by water index (*K*), (3) topographic metrics of slope steepness and length (*LS*), (4) land-cover type (C), and (5) the cultivation/conservation management factor (*CP*) (Renard and others, 1991). Whether precipitation is in the form of snow or rain and the degree of soil freezing, which are factors related to temperature, also influence erosion rates (Renard and others, 1997).

Previous research regarding rates of soil erosion by water have been primarily focused on agricultural contexts. Developing predictive soil-loss equations for other contexts is an active area of research currently. In the arid and semiarid regions of the southwestern United States, precipitation is often delivered by convective storm systems during the summer monsoon season, resulting in intense, heavy rainfall events that can result in flooding and channel erosion. Detention structures, such as check-dams (small dams across ditches or streams), have been shown to stabilize stream flow (Norman and others, 2016), retain sediment (Polyakov and others, 2014), increase soil moisture (Nichols and others, 2012), and improve riparian vegetation (Norman and others, 2014).

Check-dams are physical barriers constructed across channels meant to induce sediment deposition by slowing flow rates and decreasing channel gradient. Where runoff volumes and rates are relatively low, such as in intermittent streams where channel entrenchment or headcuts have not developed that require engineered structures, hand-built check-dams offer a low-tech approach to improving landscapes. By inducing deposition, check-dams can be used effectively for grade stabilization and erosion control, while also improving ecosystem function by redistributing water within a catchment. Retaining runoff at check-dam sites for longer time periods is expected to induce a feedback loop, where increased water resources lead to plant growth and increased vegetative cover results in increased infiltration and soil moisture (Nichols and others, 2012).

Concern over stream entrenching in the Western United States began in the early 20th century (Bryan, 1925) and continues to be a land-management concern into the future with projected climate changes likely to increase rates of soil erosion by water (Sankey and others, 2017). Historically, the North American beaver (*Castor canadensis*) occurred throughout the Southern Rockies Landscape Conservation Cooperative (SRLCC) unit (fig. 1), even in the arid intermittent streams of the region (Gibson and Olden, 2014). Research on beaver dams has shown that they alter stream hydrology, sediment dynamics, nutrient cycling, and create lentic habitats, and as a result, they alter stream flora and fauna (Naiman and others, 1986; Naiman and others, 1988; Rosell and others, 2005). Although beaver populations have grown substantially since their near extirpation (Rosell and others, 2005), large areas of modeled suitable habitat are currently unoccupied and there is a growing interest in mimicking beaver dams as a resource management tool (Gibson and Olden, 2014). Similarly, historic Native American dry-land farming techniques also incorporated the building of dams made of brush and trees in ephemeral drainages for water catchment and erosion control. Zuni Indian alluvial-fan farming techniques have shown the ability to reduce arroyo cutting, increase the frequency of overland flow events, and reconnect channels to alluvial fans (Norton and others, 2002; Pederson and others, 2006).

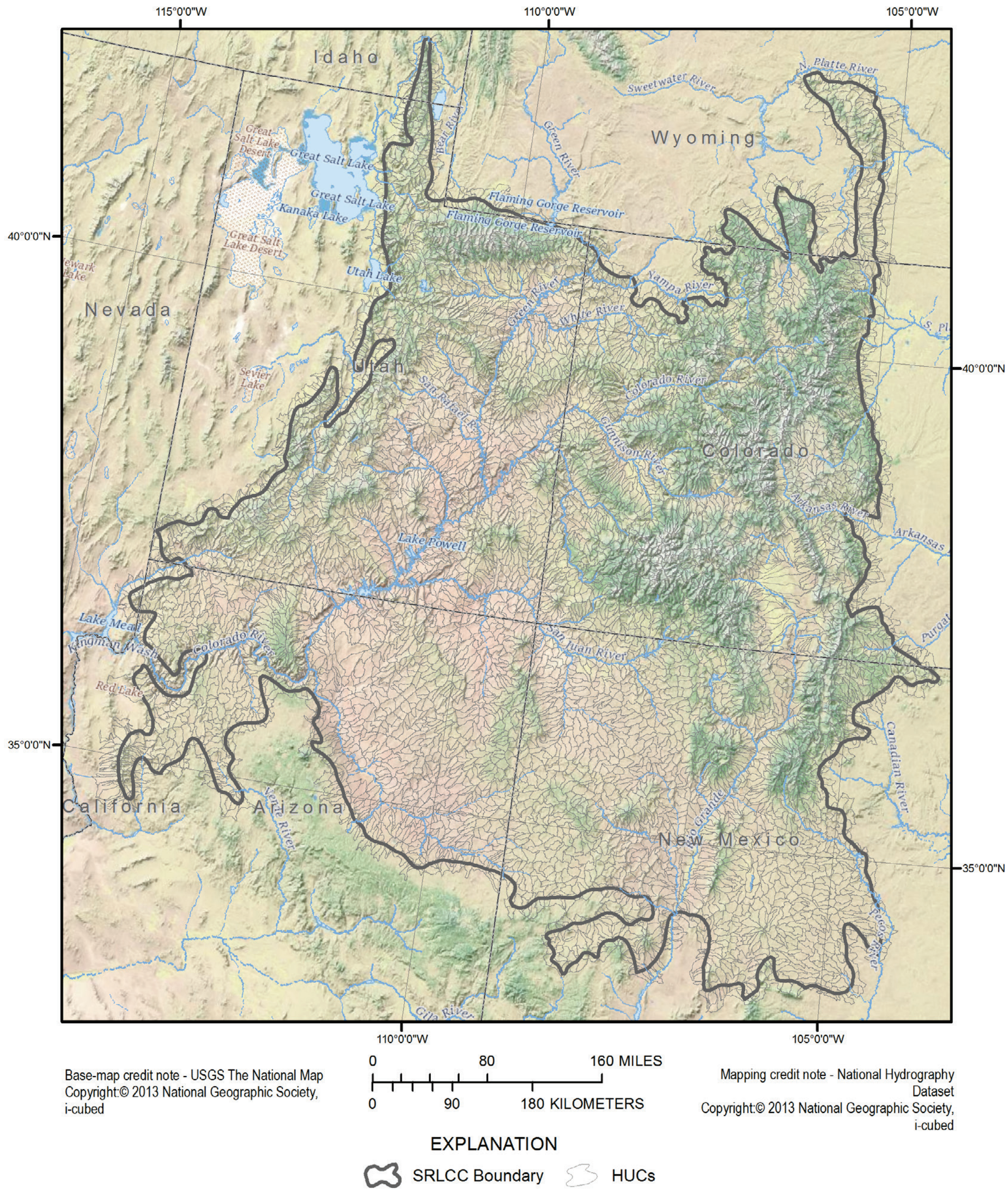

Figure 1. Study area map showing the Southern Rockies Landscape Conservation Cooperative (SRLCC) unit boundary (black line) and U.S. Geological Survey 12-digit hydrologic unit codes (U.S. Geological Survey, 2017) that intersect the SRLCC boundary. The SRLCC unit is more than 127 million acres centered on the four corners region of Arizona, Colorado, New Mexico, and Utah, and also includes parts of Idaho and Wyoming (Southern Rockies Landscape Conservation Cooperative, 2018).

The SRLCC Steering Committee has identified streams as a focal resource (see Southern Rockies Landscape Conservation Cooperative, 2018, for more information on the SRLCC formation, goals, strategies, and focus). Because of the arid climate of the SRLCC region, water is a limited resource, and stakeholders have identified stream-ecosystem conservation and management as an important need. Stream-flow management is important for both natural-resource conservation and also for societal needs (for example storage and delivery of water for human use such as irrigation, hydropower, and municipal supply). To meet the need of watershed prioritization for check-dam installation across the SRLCC, I compiled data from the best available geographic datasets for soils, terrain features, and hydrologic networks. I developed a ranking system for watersheds based on soil-slope gradient characteristics and particular landforms intersected by streams that are best suited for check-dam installation.

Methods

This section described the methods I used to develop a ranking system for watershed potential erosion rates and suitability for check-dam placement across the SRLCC. The section describes how I delineated the study area and determined the watershed ranking.

Study Area

The climate of the SRLCC unit is variable due to encompassing elevation and latitudinal gradients, resulting in different temperature ranges seasonally and diurnally. It also varies in precipitation seasonality, with the southern extent predominantly receiving summer precipitation from the North American monsoon and the northern part primarily receiving winter-storm precipitation, much of it occurring as snow in the higher elevation mountainous regions. High-elevation alpine systems occur in the Colorado Rocky Mountains and the mountain ranges of Utah. The SRLCC unit also encompasses the Grand Canyon in Arizona, which at its lowest elevations consists of Mojave Desert vegetation communities. Therefore, many biomes from shrub lands, to woodlands, to various forest types are represented within the SRLCC unit.

The SRLCC boundary was used to intersect hydrologic units from the U.S. Geological Survey (USGS) Watershed Boundary Dataset (WBD) (U.S. Geological Survey, 2017). The WBD is a nationally consistent watershed dataset that is subdivided into six levels and is available from the USGS and the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) National Cartographic and Geospatial Center (NCGC). The WBD contains the most current 8-digit, 10-digit, and 12-digit hydrologic unit codes (HUC) available. I selected the smallest watershed delineation, the 12-digit HUC that intersected the SRLCC boundary to define the study area for analysis (fig. 1).

Watershed Ranking

I obtained soil data from the NRCS Gridded Soil Survey Geographic (gSSURGO) database for Arizona, Colorado, Idaho, New Mexico, Nevada, and Utah using the USDA Geospatial Data Gateway (U.S. Department of Agriculture, 2017). The gSSURGO databases were created for use in national, regional, and statewide resource planning and analysis of soils data and can be readily combined with raster layers, including the National Land Cover Database (NLCD), the National Agricultural Statistics Service (NASS) Crop Data Layer (CDL), and the National Elevation Dataset (NED) (Natural Resources Conservation Service, 2017). I queried the gSSURGO databases for K (the soil water erodibility factor), which is a soil metric based on soil texture, chemistry, and organic matter content. NRCS provides two K metrics, one for the whole soil horizon that includes rock fragments, *kwfact*, and one for the fine soil (no rock fragments), *kffact*. As *K* increases, the more susceptible the soil is to water erosion. Each gSSURGO map unit polygon has a one to many relation with the factor fields for *K*. Each map unit in gSSURGO has one or more components, and each component has one or more soil horizons. To estimate *K* for a single map unit, I calculated the average *K* value across horizons. When horizon thickness values were provided, I used a weighted average by thickness of the soil horizon. When the soil horizon *K* was provided for the whole soil, *kwfact* was used as *K*; and when not provided, *kffact* was used was used as *K*. The average *K* across soil horizons for the soil component was then averaged again by a weighted average using the component percentage of the map unit to determine the final map unit *K* value.

SSURGO soil data are not currently available for the entire study area (fig. 2*A*). Coarser spatial resolution NRCS soil data are available for these regions, and map unit *K* has been previously compiled for the United States using data from Miller and White (1998) by the Pennsylvania State University Soil Information for Environmental Modeling and Ecosystem Management program (Pennsylvania State University, 2006). *K* for the whole soil was obtained from the contiguous United States (CONUS) dataset by downloading the ArcINFO coverage in the Albers projection (Pennsylvania State University, 2006) (fig. 2*B*). The map unit source data from the gSSURGO and CONUS datasets were converted to a 90-meter (m) resolution raster dataset using the majority function in Esri ArcGIS version 10.3 software (Esri, 2013), which provided *K* estimates for the entire SRLCC except parts of the Grand Canyon below its rim (fig. 2*C*).

Slope gradients also play an important role in the potential for soil erosion by water (Miller and others, 2011; Pederson and others, 2006). I calculated slope in degrees using a ~30-m digital elevation model (DEM) (U.S. Geological Survey, 2009), resampled to the 90-m resolution of the *K* grids using bilinear resampling in Esri ArcGIS version 10.3 software (Esri, 2013). *K* was multiplied by slope and summed by watershed using ArcGIS Spatial Analyst toolbox zonal statistics, resulting in a relative index of the potential for erosion due to soil properties and slope for the 12-digit HUC watersheds (fig. 3). Watersheds were selected that contained an intermittent or perennial stream identified using the U.S. Rivers and Streams dataset in ArcGIS (Esri, 2012), which consists of intermittent and perennial streams, washes, and arroyos that are connected to higher order streams and rivers. This dataset was clipped to the study area and a subset of the dataset created to only include feature types of "Stream/River." Closed watersheds are considered here to be low priority for check-dam installation, and watersheds with streams that could transport sediments to rivers and reservoirs are only considered for ranking (fig. 3).

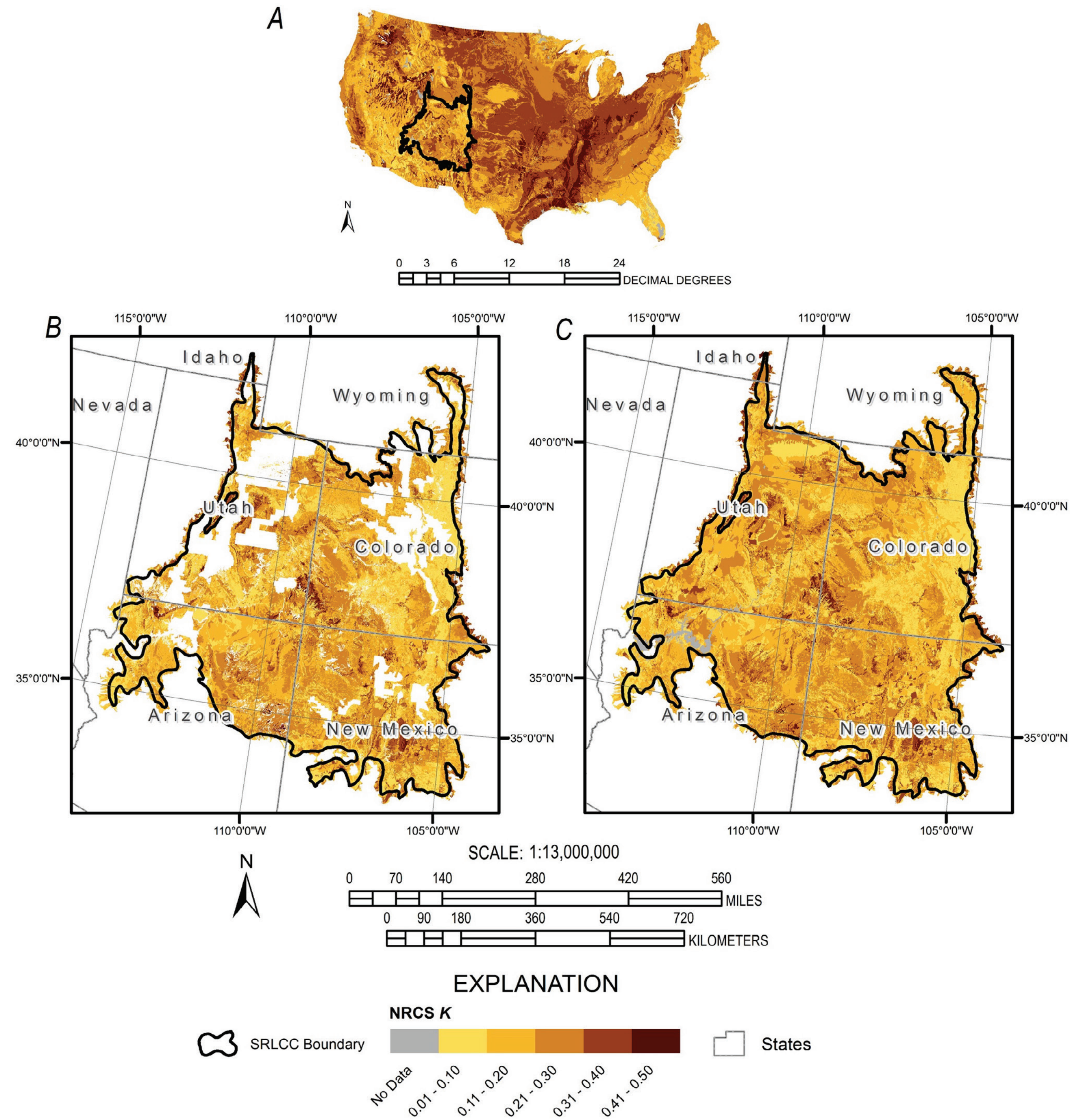

Figure 2. Maps showing currently available Natural Resources Conservation Service (NRCS) (2017) soil type erodibility by water index (K) for the area of the Southern Rockies Landscape Conservation Cooperative (SRLCC). A, Map showing soil data available for the contiguous United States (Pennsylvania State University, 2006). B, Map showing finer resolution Gridded Soil Survey Geographic (gSSURGO) data available for parts of the SRLCC (U.S. Department of Agriculture, 2017). C, Map showing data from Pennsylvania State University (2006) used to provide information for gaps in the gSSURGO data for K to cover the watersheds of the SRLCC except for parts of the Grand Canyon where no data are available from either dataset.

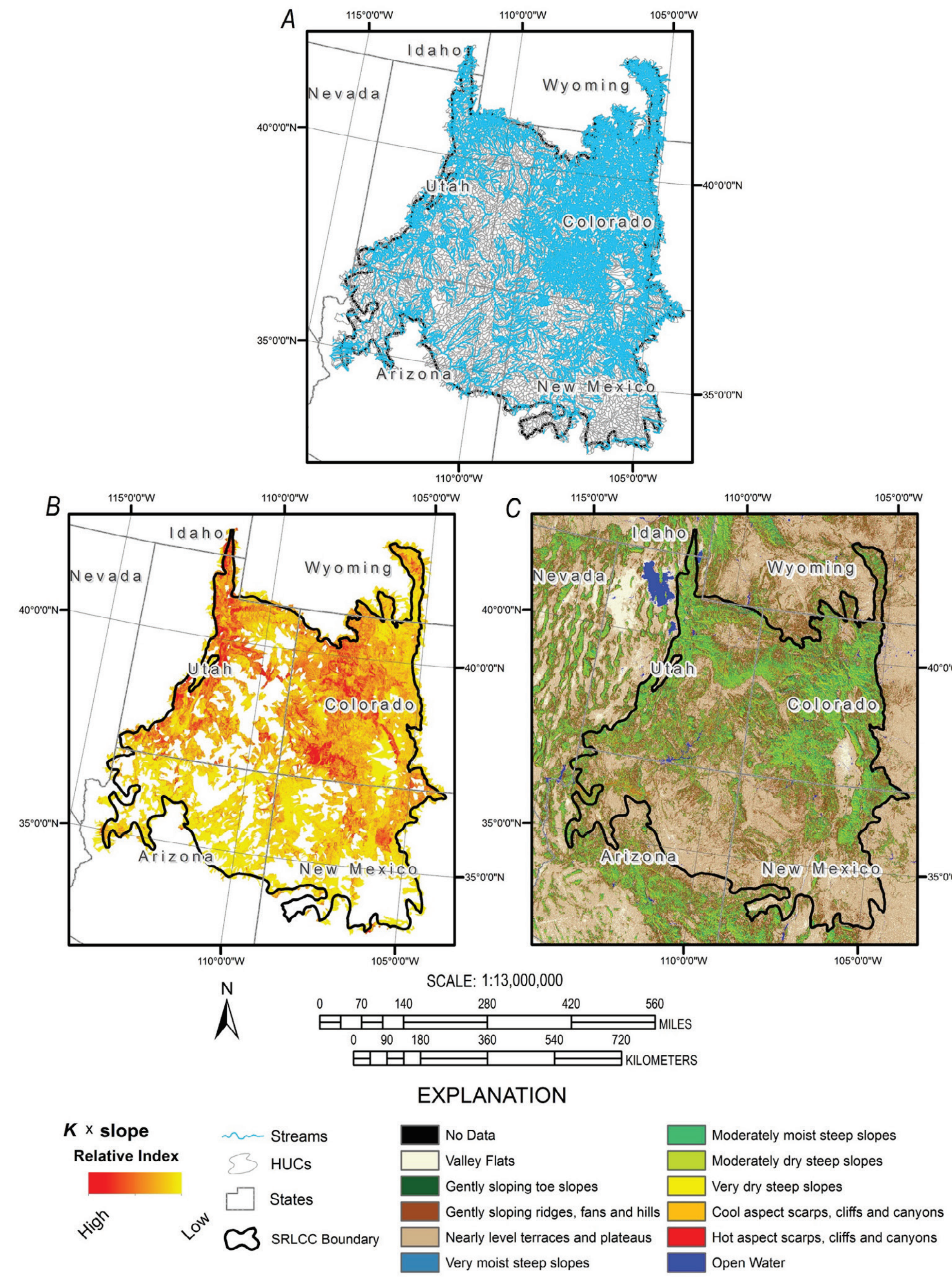

Figure 3. Maps showing spatial datasets used for developing the ranking system for Southern Rockies Landscape Conservation Cooperative watersheds. *A*, U.S. perennial and intermittent steams data (Esri, 2012). *B*, Slope gradient (degrees; from U.S. Geological Survey, 2009) multiplied by *K*, *C*, A landform classification system (Manis and others, 2001). HUCs, U.S. Geological Survey 12-digit hydrologic units codes (U.S. Geological Survey, 2017).

Beaver dams and check-dams have been found to be most effective on particular landforms such as gentle slopes and alluvial fans, where the dams result in more overland flow events, result in stream-flow stabilization, and can promote the growth of riparian or semi-riparian plant species. Dams in streams along steep slopes and narrow draws are often damaged and are less effective at catching sediment (Pederson and others, 2006; Rosell and others, 2005). I developed another index to identify stream check-dam suitability using a landform classification system. I used a 90-m resolution DEM and the Arc Macro Language script developed by Manis and others (2001) to define 10 landform classes. I also added another class by extracting and adding a water body class from resampled 30-m USDA/USGS LANDFIRE data (LANDFIRE, 2011) to show areas of frequent inundation (fig. 3*D*). I reclassified the landform raster, giving the classes of "gently sloping toe slopes" and "gently sloping ridges, fans and hills" a value of one and the remaining classes a value of zero. I converted the stream line features into a raster dataset and assigned perennial streams a value of two and intermittent steams a value of one based on the FCODE_DESC field. These two raster datasets were multiplied together in Esri's Spatial Analyst raster calculator, resulting in a raster showing where streams traverse landforms classified as "gently sloping toe slopes" and "gently sloping ridges, fans and hills." I used zonal statistics to sum this check-dam suitability raster by watershed, which results in an indication of the amount of area (number of cells) where check-dams would be suitable to install, weighting the sum towards perennial streams over intermittent streams.

The final steps in developing our watershed ranking system included multiplying the watershed potential for water erosion index (the sum of K × slope index per watershed, fig. 3*C*) by the check-dam suitability index. This resulted in an index quantifying a watershed's potential for erosion and also its suitability for check-dam installation. Because the climate of the SRLCC is highly variable due to elevation and latitudinal gradients, there is a fair amount of variability in soil temperatures, degree of freezing, and precipitation. Soil temperature, the length of time a soil is frozen, and whether or not precipitation is in the form of rain or snow both impact erosion rates. I further subdivided the SRLCC into climatic zones based on isotherms and precipitation seasonality to identify watersheds that experience similar climatic patterns for the final ranking system. I used the BioClim dataset accessed from WorldClim (2017) to parse regions within the SRLCC of similar climates using the variables of precipitation seasonality (BIO_{15}) and isothermality (BIO_3). Precipitation seasonality is calculated using the coefficient of variation in precipitation. Isothermality is calculated by dividing the mean diurnal range (that is, the mean of monthly maximum temperature minus the minimum temperature) by the annual range of temperature (that is, maximum temperature of the warmest month minus the minimum temperature of the coldest month) times 100. BIO_3 and BIO_{15} were multiplied together for the study area to create an index of climatic similarity across the SRLCC (fig. 4). Using equal interval classification and six bins to define distinct climatic subregions, I assigned the SRLCC 12th level HUC watershed to the six climatic regions. Final watershed ranking from highest priority to lowest was done by climatic subregion (fig 5).

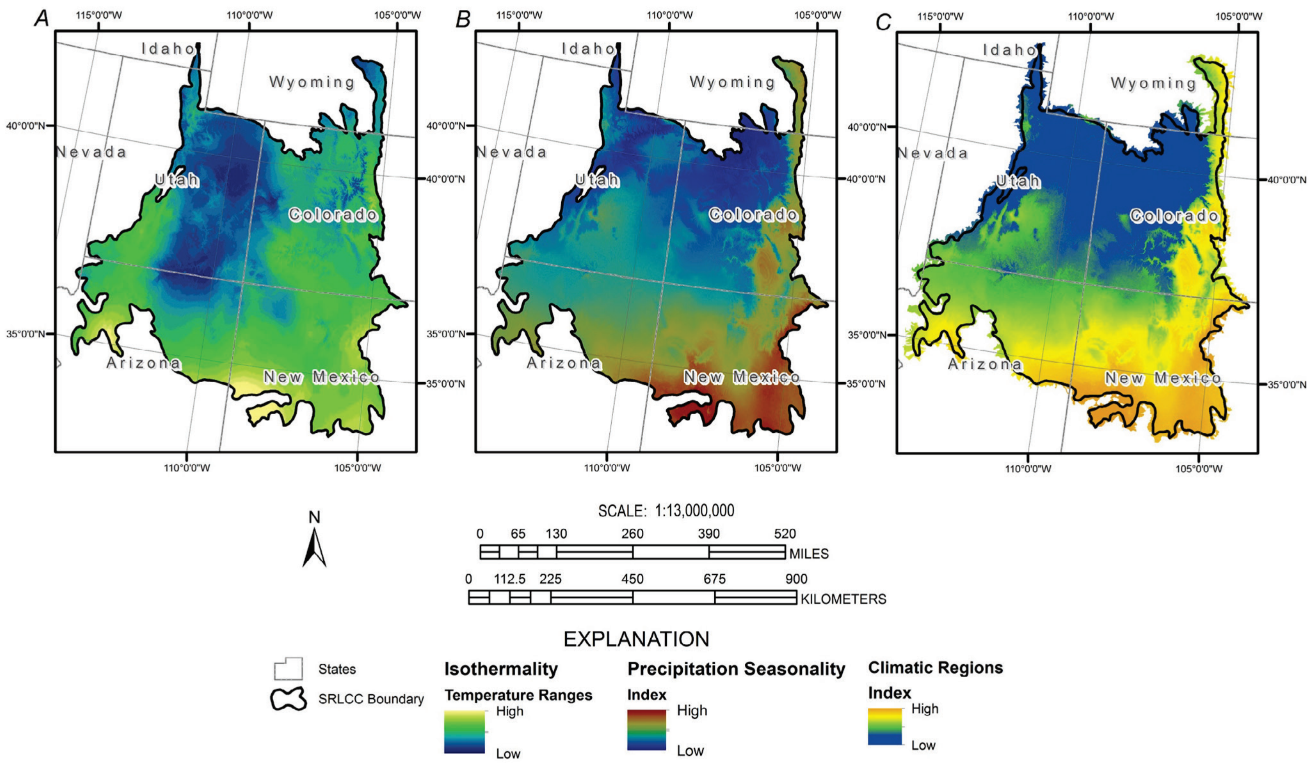

Figure 4. Maps showing BioClim datasets (accessed from WorldClim, 2017) used to develop similar climatic regions on which to rank Southern Rockies Landscape Conservation Cooperative (SRLCC) watersheds. *A*, Isothermality (BIO_3, a metric of temperature ranges) and, *B*, precipitation seasonality (BIO_{15}) were used to create, *C*, an index of how climate varies across the SRLCC.

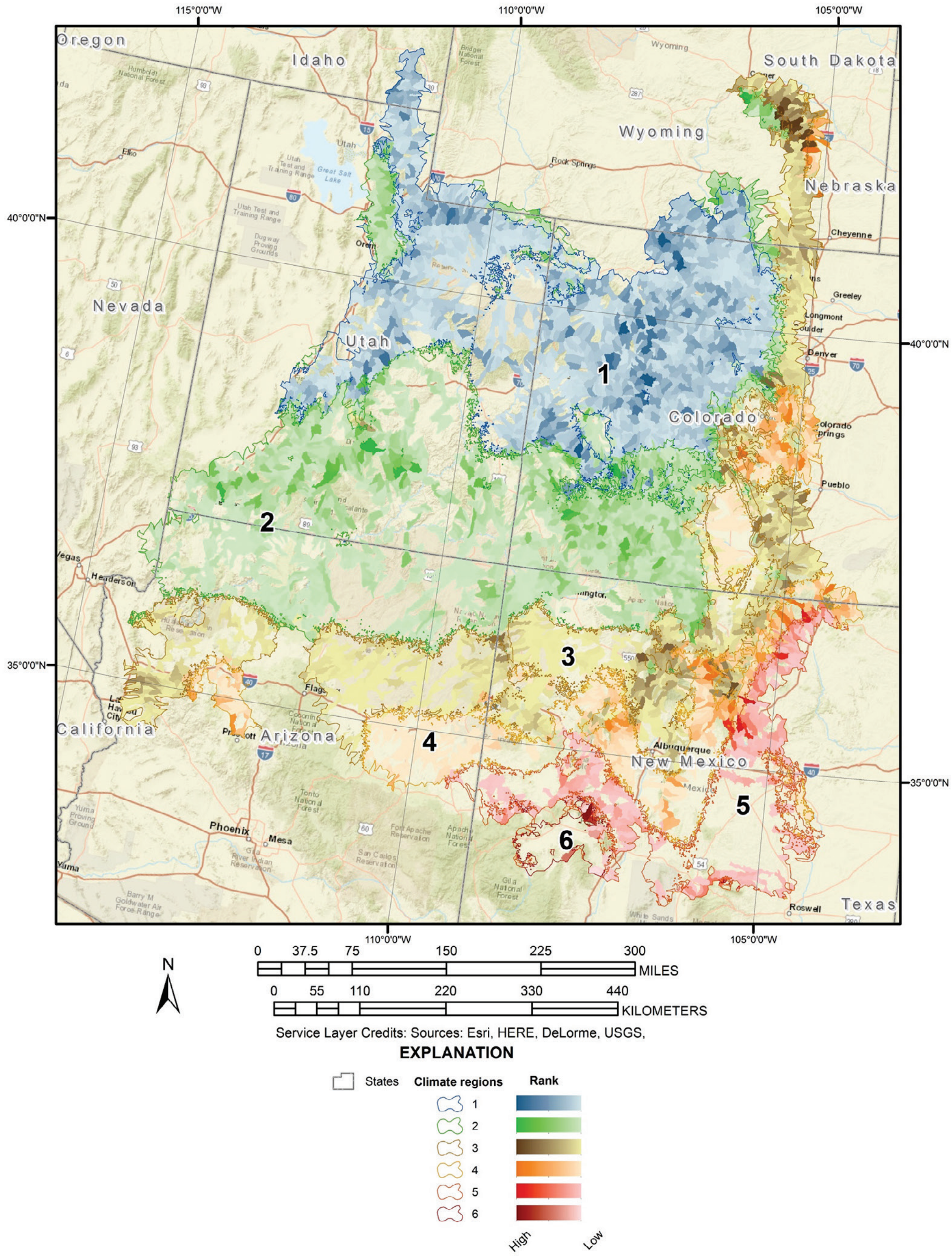

Figure 5. Maps showing watershed ranking results for the six climatic regions in the Southern Rockies Landscape Conservation Cooperative (SRLCC) unit. Maps of watershed ranking based on erosion potential of soil by water and the landforms streams traverse for regions 1 through 6, respectively.

Results

Using the WBD's (U.S. Geological Survey, 2017) smallest watershed designation, 12-digit HUCs, resulted in selecting 6,255 watersheds for the analysis of the SRLCC region. Of these watersheds, 4,442 watersheds were found to have intermittent or small perennial streams that are connected to the larger stream, river, and reservoir systems of the SRLCC. These watersheds were evaluated for their soil properties (Natural Resources Conservation Service, 2017, soil type erodibility by water index, *K*), slope gradients, and landforms traversed by streams for identifying watersheds that could benefit from check-dam installation (Ironside, 2018). I identified six climatic regions within the SRLCC that had similar temperature ranges and precipitation patterns. Region 1, consisting of 1,626 HUCs, is located in the northern SRLCC and is characterized by high-elevation mountainous areas of Utah and Colorado, where precipitation is winter dominated and often comes in the form of snow (Knowles and others, 2006). The streams of this region are characterized by springtime runoff from snow melt. Region 2 consists of the four corners area of the Colorado Plateau Province and contains 2,175 HUCs. This region experiences a bimodal precipitation regime— (1) winter precipitation sometimes in the form of snow and (2) summer monsoon precipitation. Region 3 consists of 1,183 HUCs and encompasses parts of northern Arizona, New Mexico, and the lower elevation part of the Rocky Mountains in Colorado and Wyoming. This region experiences relatively large temperature fluctuations and also a relatively large degree of variability in precipitation seasonality. Region 4, 719 HUCs, consists of the lower elevation HUCs that include the SRLCC parts of Arizona, New Mexico, Colorado, and Wyoming where precipitation can be bimodal but tends to occur in the form of rain. Region 5, with 471 HUCs, is located in New Mexico and is characterized by receiving a fair amount of monsoon precipitation and also has large temperature ranges. Region 6 is small, with only 73 HUCs, but is a climatically unique area of the SRLCC. This region, located in west central New Mexico, ranks the highest in both the isotherm and precipitation seasonality indices (fig. 5).

Region 1

Region 1 is the second largest climatic subregion of the SRLCC. It had many watersheds with a high index ranking located in the Uinta and Wasatch Mountain ranges of Utah, and the Uncompahgre Plateau and the Rocky Mountains of northern Colorado into Wyoming (Ironside, 2018).

Region 2

Region 2, the largest climatic subregion of the SRLCC, had many watersheds with a high index ranking. Many of the northern watersheds placed in the climatic subregion of the SRLCC ranked relatively high. Other watershed of high ranking occurred in southern Utah, in the Henry Mountains, Escalante area, and the Sevier Plateau. The San Juan Mountains of southwestern Colorado also had a high concentration of high-ranking watersheds (Ironside, 2018).

Region 3

The Laramie Mountains of Wyoming and the Front Range of Colorado parts of region 3 had the highest concentration of high-ranking watersheds. The Nacimiento Mountains of New Mexico also ranked high for prioritization of check-dam installation, along with parts of the Sangre de Cristo Mountains (Ironside, 2018).

Region 4

Region 4 had similar results to region 3, where watersheds ranked high in similar areas. Many of the lower elevation watersheds of the Laramie Mountains of Wyoming, the Front Range of Colorado, and the Nacimiento and Sangre de Cristo mountain ranges of New Mexico were found to rank high. For Arizona, some watersheds around the Sullivan Buttes and Mohon Mountain area, northwest of Prescott, ranked high (Ironside, 2018).

Region 5

The region 5 subregion is located in New Mexico and had watersheds ranking high east of the Santa Fe area and Sangre de Cristo Mountains. Three watersheds also ranked high in the Vera Cruz Mountains (Ironside, 2018).

Region 6

Region 6 is a small subregion. It had two watersheds that ranked highest—the Jaralosa Creek and the Dry Lake Canyon watersheds located in the Gallina Mountains (Ironside, 2018).

Discussion

Erosion has been a land-management concern in the region of the SRLCC over the past century. I provide a watershed ranking system across the SRLCC based on two of the most relatively static contributors to water erosion—Natural Resources Conservation Service (2017) soil type erodibility by water index (*K*) and slope gradient. Because of the landscape scale of this assessment and the long-term goals of using check-dams for future erosion control efforts, I did not include the more dynamic factors of precipitation intensity and cover that contribute to soil erosion rates. Precipitation intensity and cover (vegetative, physical soil crusting, biological soil crusts, crops) also play an important role in determining erosion rates (Bowker and others, 2008; Miller and others, 2011). These rather local and dynamic factors over time could also be considered by resource managers as the next step to prioritizing their local management areas for check-dam installation. Many other relatively dynamic factors over time can contribute to soil erosion rates, such as recent wildfire events, changes in weather patterns and extreme events (Sankey and others, 2017; Segura and others, 2014), and changing land-use such as grazing (Bryan, 1925), logging, mining, development, and agriculture. Information on the extent of existing beaver dams and existing check-dams across the SRLCC was not readily available for inclusion in my analysis; these are other factors that stakeholders may have local knowledge of to further prioritize watersheds within their jurisdiction.

Predicting actual stream sediment yields has proven difficult. Both the RUSLE (Renard and others, 1991) and the Geo-spatial interface of the Water Erosion Prediction Project (GeoWEPP; Renschler, 2003) model underestimated post-fire erosion rates when compared to actual measured erosion rates in Colorado (Miller and others, 2011). More research is needed to improve both relative and absolute accuracy of predicted erosion rates. Currently there are no simple, physically based methods for determining the appropriate critical source area and minimum source channel length values in response to variations in climate, soils, vegetation, and burn severity across the entire study area. More detailed studies of erosion-model parametrization sensitivity are needed to determine the relative importance of the different parameters in the plant-management files of predictive models such as GeoWEPP (Miller and others, 2011).

Conclusion

Several studies have shown the benefits of rigid, brush, and beaver dams on small streams and how they can also benefit downstream riparian systems. Because of the size of the SRLCC unit, a landscape-scale assessment was needed to begin prioritization of watersheds for stream restoration efforts using check-dams. This assessment, along with the existing literature that primarily covers forested landscapes, will be useful for identifying areas to target for stream restoration.

References Cited

Bowker, M.A., Belnap, J., Bala Chaudhary, V., and Johnson, N.C., 2008, Revisiting classic water erosion models in drylands—The strong impact of biological soil crusts: Soil Biology and Biochemistry, v. 40, no. 9, p. 2309–2316, accessed on June 2017, at https://doi.org/10.1016/j.soilbio.2008.05.008.

Bryan, K., 1925, Date of channel trenching (arroyo cutting) in the arid southwest: Science, v. 62, no. 1607, p. 338–344, accessed on June 2017, at http://www.jstor.org/stable/1648948.

Esri, 2012, ArcGIS U.S. Rivers and Streams, version 10: Esri dataset.

Esri, 2013, ArcGIS desktop, version 10.2: Esri software, accessed on June 2017, at http://www.esri.com/.

Gibson, P.P., and Olden, J.D., 2014, Ecology, management, and conservation implications of North American beaver (*Castor canadensis*) in dryland streams: Aquatic Conservation—Marine and Freshwater Ecosystems, v. 24, no. 3, p. 391–409, accessed on June 2017, at https://doi.org/10.1002/aqc.2432.

Ironside, K.E., 2018, Watershed potential erosion rate ranking system and check-dam placement suitability data within the Southern Rockies Landscape Conservation Cooperative (SRLCC): U.S. Geological Survey data release, https://doi.org/10.5066/P9SEUC93.

Knowles, N., Dettinger, M.D., and Cayan, D.R., 2006, Trends in snowfall versus rainfall in the Western United States: Journal of Climate, v. 19, no. 18, p. 4545–4559, accessed on August 2018, at https://doi.org/10.1175/JCLI3850.1.

LANDFIRE, 2011, LANDFIRE 1.1.0—Existing vegetation height and type layers in LANDFIRE (1.1.0 ed.): U.S. Department of Agriculture and U.S. Geological Survey, accessed on June 2017, at https://landfire.gov/.

Manis, G., Lowry, J., and Ramsey, R.D., 2001, Preclassification—An ecologically predictive landform model: Moscow, Idaho, U.S. Geological Survey GAP Analysis Program Bulletin, no. 10. [Also available at https://pubs.usgs.gov/gap/10/report.pdf.]

Miller, D.A., and White, R.A., 1998, A conterminous United States multi-layer soil characteristics data set for regional climate and hydrology modeling: Earth Interactions, v. 2, no. 2, 26 p. [Also available at https://doi.org/10.1175/1087-3562(1998)002<0001:ACUSMS>2.3.CO;2.]

Miller, M.E., MacDonald, L.H., Robichaud, P.R., and Elliot, W.J., 2011, Predicting post-fire hillslope erosion in forest lands of the western United States: International Journal of Wildland Fire, v. 20, no. 8, p. 982–999, accessed on June 2017, at https://doi.org/10.1071/WF09142.

Naiman, R.J., Johnston, C.A., and Kelley, J.C., 1988, Alteration of North American streams by beaver—The structure and dynamics of streams are changing as beaver recolonize their historic habitat: BioScience, v. 38, no. 11, p. 753–762, accessed on June 2017, at https://doi.org/10.2307/1310784.

Naiman, R.J., Melillo, J.M., and Hobbie, J.E., 1986, Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*): Ecology, v. 67, no. 5, p. 1254–1269, accessed on June 2017, at https://doi.org/10.2307/1938681.

Natural Resources Conservation Service, 2017, Description of Gridded Soil Survey Geographic (gSSURGO) database: Natural Resources Conservation Service web page, accessed November 2, 2017, at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053628.

Nichols, M.H., McReynolds, K., and Reed, C., 2012, Short-term soil moisture response to low-tech erosion control structures in a semiarid rangeland: Catena, v. 98, p. 104–109, accessed on June 2017, at https://doi.org/10.1016/j.catena.2012.06.010.

Norman, L., Villarreal, M., Pulliam, H.R., Minckley, R., Gass, L., Tolle, C., and Coe, M., 2014, Remote sensing analysis of riparian vegetation response to desert marsh restoration in the Mexican highlands: Ecological Engineering, v. 70, p. 241–254, accessed on June 2017, at https://doi.org/10.1016/j.ecoleng.2014.05.012.

Norman, L.M., Brinkerhoff, F., Gwilliam, E., Guertin, D.P., Callegary, J., Goodrich, D.C., Nagler, P.L., and Gray, F., 2016, Hydrologic response of streams restored with check dams in the Chiricahua Mountains, Arizona: River Research and Applications, v. 32, no. 4, p. 519–527, accessed on June 2017, at https://doi.org/10.1002/rra.2895.

Norton, J.B., Bowannie, F., Peynetsa, P., Quandelacy, W., and Siebert, S.F., 2002, Native American methods for conservation and restoration of semiarid ephemeral streams: Journal of Soil and Water Conservation, v. 57, no. 5, p. 250–258, accessed on June 2017, at http://www.jswconline.org/content/57/5/250.abstract.

Osterkamp, W.R., 2008, Annotated definitions of selected geomorphic terms and related terms of hydrology, sedimentology, soil science and ecology: U.S. Geological Survey Open-File Report 2008–1217, 49 p., accessed on June 2017, at http://pubs.er.usgs.gov/publication/ofr20081217.

Pederson, J.L., Petersen, P.A., and Dierker, J.L., 2006, Gullying and erosion control at archaeological sites in Grand Canyon, Arizona: Earth Surface Processes and Landforms, v. 31, no. 4, p. 507–525, accessed on June 2017, at http://dx.doi.org/10.1002/esp.1286.

Pennsylvania State University, 2006, Soil information for environmental modeling and ecosystem management: Pennsylvania State University website, accessed July 15, 2017, at http://www.soilinfo.psu.edu/index.cgi?soil_data&conus&data_cov&k&datasets&alb.

Polyakov, V.O., Nichols, M.H., McClaran, M.P., and Nearing, M.A., 2014, Effect of check dams on runoff, sediment yield, and retention on small semiarid watersheds: Journal of Soil and Water Conservation, v. 69, no. 5, p. 414–421, accessed on June 2017, at http://www.jswconline.org/content/69/5/414.abstract.

Renard, K.G., Foster, G.R., Weesies, G.A., and Porter, J.P., 1991, RUSLE—Revised universal soil loss equation: Journal of Soil and Water Conservation, v. 46, no. 1, p. 30–33, accessed on June 2017, at http://www.jswconline.org/content/46/1/30.short.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C., 1997, Predicting soil erosion by water—A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE): Washington, D.C., U.S. Department of Agriculture, Agricultural Research Service, Agriculture Handbook 703, 407 p., accessed on June 2017, at https://www.ars.usda.gov/ARSUserFiles/64080530/rusle/ah_703.pdf.

Renschler, C.S., 2003, Designing geo-spatial interfaces to scale process models—The GeoWEPP approach: Hydrological Processes, v. 17, no. 5, p. 1005–1017.

Rosell, F., Bozsér, O., Collen, P., and Parker, H., 2005, Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems: Mammal Review, v. 35, no. 3–4, p. 248–276, accessed on June 2017, at http://dx.doi.org/10.1111/j.1365-2907.2005.00067.x.

Sankey, J.B., Kreitler, J., Hawbaker, T.J., McVay, J.L., Miller, M.E., Mueller, E.R., Vaillant, N.M., Lowe, S.E., and Sankey, T.T., 2017, Climate, wildfire, and erosion ensemble foretells more sediment in western USA watersheds: Geophysical Research Letters, v. 44, no. 17, p. 8884–8892, accessed on June 2017, at http://dx.doi.org/10.1002/2017GL073979.

Segura, C., Sun, G., McNulty, S., and Zhang, Y., 2014, Potential impacts of climate change on soil erosion vulnerability across the conterminous United States: Journal of Soil and Water Conservation, v. 69, no. 2, p. 171–181, accessed on June 2017, at http://www.jswconline.org/content/69/2/171.abstract.

Southern Rockies Landscape Conservation Cooperative, 2018, About: Southern Rockies Landscape Conservation Cooperative web page, accessed April 23, 2018, at https://southernrockieslcc.org/about.

U.S. Department of Agriculture, 2017, Geospatial data gateway: U.S. Department of Agriculture web page, accessed June–August, 2017, at https://gdg.sc.egov.usda.gov/.

U.S. Geological Survey, 2009, National Elevation Dataset (NED) (2nd ed.): U.S. Geological Survey, accessed on June 2017, at https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned.

U.S. Geological Survey, 2017, Watershed Boundary Dataset: U.S. Geological Survey dataset, accessed on June 20, 2017, at https://water.usgs.gov/GIS/huc.html.

WorldClim, 2017, Bioclimatic variables: WorldClim-Global Climate Data dataset, accessed June 1, 2017, at http://www.worldclim.org/bioclim.

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