Missouri Headwaters Riparian and Rangeland Tool

Metadata and Methodology

The Nature Conservancy
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Rapid City, SD

March 2019

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This project was made possible through grant funding from the National Fish and Wildlife Foundation and ConocoPhillips SPIRIT of Conservation and Innovation Award.

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Background

Riparian areas are among the most critical, heavily used, and declining habitats within the northern Great Plains grasslands. Sage grouse, grassland birds, large game, bats, and other wildlife all depend on riparian health for nourishment, habitat, and landscape connectivity within the Missouri River headwaters. Riparian areas are also essential for the success of ranchers within the landscape that depend on prairie streams to water livestock. Yet, these areas are also lacking targeted conservation analysis to identify areas of the landscape that are properly functioning, versus areas where habitat restoration, connectivity, or other conservation measures are needed – and at what scale –to improve landscape resiliency for people and nature.

This project, led by The Nature Conservancy in MN, ND, SD with funding from the National Fish and Wildlife Foundation, sought to convene resource professionals and federal, state and NGO partners and stakeholders working within this grassland landscape to provide input on targeted analysis that would identify conservation and restoration needs and priorities. We compiled spatial data and information regarding landscape characteristics and condition; conducted analysis and modeling designed to inform collaborative management; and developed an online web mapping tool intended to assist partners in determining what conservation measures are needed and where to provide the most benefit utilizing limited resources. The tool allows the user to explore a series of maps and data layers organized into "modules" describing rangeland potential, catchment potential, and riparian potential condition in landscape context.

This metadata document describes the methodology and sources for the data presented in the tool. "Explorer modules" within the mapping tool are designed to help users and partners understand the landscape, watershed, and catchment context and identify areas of potential focus and priority need. Users can navigate within each of these modules understand how catchments relate to each other in terms of potential for health and function at the landscape scale.

*NOTE: The tool is designed to be compatible with the web navigation/software browsers in most common use as of 2019. For best performance, use with Microsoft Chrome or Mozilla Firefox.

Supporting Layers

General Physical and Ecological Info
Rangeland Potential
Catchment Potential
Riparian Potential
Biodiversity
Management and Restoration

General Physical and Ecological Info

This module contains a set of layers designed to provide basic context on the area in terms of landscape classification, physical features, land cover, topography, etcetera. It is composed of 11 layers:

1. Major Land Resource Areas
2. Ecoregion (Level IV EPA)
3. National Wetlands Inventory (NWI)
4. Land Use Land Cover (NLCD)
5. Biophysical Setting Potential Vegetation
6. Soil Taxonomic Order
7. Slope (%)
8. Active Riparian Area
9. Total Drainage Area (Sq Km)
10. Mean Annual Flow (cfs)
11. Runoff

1. **Major Land Resource Areas** (MLRA) are geographically associated land resource units delineated by the Natural Resources Conservation Service and characterized by a particular pattern that combines soils, water, climate, vegetation, land use, and type of farming. Identification of these large areas is important in statewide agricultural planning and has value in interstate, regional, and national planning. The Little Missouri Headwaters landscape of northwest SD, southwest ND, southeast MT, and northeast WY overlaps with 8 MLRAs, including the eastern and northern part of the Northern Rolling High Plains of northwest SD, the Rolling Soft Shale Plains in the headwaters of the Grand and Moreau Rivers, and the Pierre Shale Plains and Badlands that dominates the Belle Fourche River watershed. For more information on MLRAs, visit the NRCS web site at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053624

2. **Ecoregion (Level IV EPA).** Ecoregions represent areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. The EPA ecoregional framework is a hierarchical framework derived from Omernik (1987) and mapping done in collaboration with EPA regional offices, other Federal agencies, state resource management agencies, and neighboring North American countries. Ecoregions are designed to serve as a spatial framework for environmental resource management. The Level IV ecoregions are the fourth level within the hierarchy, describing detailed subdivisions of the Level III, II, and I ecological regions. See: https://www.epa.gov/eco-research/ecoregions

3. **National Wetlands Inventory (NWI)** is a publicly available resource created and maintained by the US Fish and Wildlife Service (FWS), the principal US federal agency tasked with providing information to the public on the status and trends of our Nation's wetlands. The NWI provides detailed information on the abundance, characteristics and distribution of US wetlands. See https://www.fws.gov/wetlands/ .

4. **Land Use Land Cover (NLCD**) The National Land Cover Database (NLCD) is a comprehensive land cover product, derived from decadal Landsat satellite imagery and other supplementary datasets. The NLCD is created and maintained through the Multi-Resolution Land Characteristics (MRLC) consortium, a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications. https://www.mrlc.gov/

5. **Biophysical Setting Potential Vegetation** Represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the biophysical environment and an approximation of the historical disturbance regime. Based on NatureServe's (NS) Ecological Systems classification as interpreted through the LANDFIRE effort. For more information see https://www.landfire.gov/bps.php

6. **Soil Taxonomic Order** The most general level of classification in the USDA system of Soil Taxonomy. Assigned based on dominant soil order for SSURGO polygons based on the SSURGO table variable "taxorder". For definitions of dominant soil orders, see https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/maps/?cid=nrcs142p2_053589

7. **Slope (%)** The slope grid is derived in ArcMap 10.3 using the Slope tool in Spatial Analyst http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/slope.htm and the 10m Digital Elevation Model (DEM) compiled for the study area (USGS National Elevation Dataset)

8. **Active Riparian Area** Represents the maximum potential extent of active riparian and floodplain area function and processes; derived via topographic and terrain analysis using a 10m DEM. The Active River Area is based on a conceptual and spatially explicit framework incorporating the dominant processes and disturbance regimes to identify areas within which important physical and ecological processes of rivers or streams occur. Key subcomponents of the active river area include: 1) material contribution zones, 2) meander belts, 3) riparian wetlands, 4) floodplains and 5) terraces (Smith et al. 2008). We adapted techniques developed by TNC Eastern Region to spatially delineate the riparian active river area components using topographic analysis with 10m and 30m DEM and 1:24,000 and/or 1:100,000 hydrography. The ARA includes a riparian base zone delineated using cost distance modeling and a material contribution zone using variable thresholds based on stream size class.

9. **Total Drainage Area (Sq Km)** Depicts total upstream catchment drainage area by NHD catchment from TotDASqKm variable attribute tables included with the NHD product set https://www.usgs.gov/core-science-systems/ngp/national-hydrography.

10. **Mean Annual Flow (cfs)** This layer depicts mean annual average streamflow estimate (cfs) using MAFLOWV variable from attribute tables included with the NHD product set https://www.usgs.gov/core-science-systems/ngp/national-hydrography.

11. **Runoff** Mean annual runoff (mm) using RunOffVC variable from the National Hydrography Dataset https://www.usgs.gov/core-science-systems/ngp/national-hydrography.

Condition Models and Their Components

RANGELAND POTENTIAL

The Rangeland Potential module includes a set of map layers and components that in aggregate reflect rangeland potential condition, represented at the catchment scale. Component layers included in the overall rangeland potential ranking include measures of intact grass cover as well as vegetation production and variability across wet and dry periods as derived from the NDVI.

Range potential overall is ranked "Low" to "Highest" based primarily on rangeland soil productivity and observed NDVI for intact grassland cover. Relative rank is based on catchment scores for the component layers, which are in turn derived from the component rasters. Catchment values were calculated for five component layers: rangeland soil productivity index, 12 year mean NDVI (grass only), mean dry year NDVI (grass only), mean wet year NDVI (grass only), and the percentage of the catchment that meets the dry year mesic threshold. Each component was ranked by quartile. These quartile ranks were then summed, with each component weighted equally, to create the final relative "range potential" index.

Components. Below we describe the components used to characterize range potential above based on information summarized at the catchment scale.

Percent grass. Percent of grasslands, herbaceous wetlands, and shrublands at the catchment scale, based on NLCD 2011.[1]

Mean Rangeland Productivity. SSURGO soil estimated mid-range value for annual potential production of range forage per year (rsprod_r). Metadata for SSURGO soil variables can be found in the NRCS SSURGO documentation.

Percent Mesic, dry years. Percent of catchment that exceeds NDVI threshold value (40) for mesic conditions during dry years, indicating greater availability of moisture, wetland or riparian habitats. "Mesic" habitat refers to land with a well-balanced supply of moisture throughout the growing season, such as streamsides, wet meadows, springs and seeps, irrigated fields and high-elevation habitats. Where land is in native vegetation, it is an indicator of the more productive riparian habitats, i.e. those habitats upon which so much grassland wildlife and livestock are dependent, especially during dry periods. The selection of an NDVI threshold value of 40 for mesic conditions is based on an approach developed for the Sage Grouse Initiative in the Colorado Gunnison sage grouse area as well as the value used for mesic habitats in the SGI tool (Chapman, pers. comm; see section on Sage Grouse Initiative tool). For the Little Missouri Headwaters region, it represents a relatively median value for the NDVI. During wet years, the threshold value of 40 for wetlands is greater than the mean across the study, but the mean value for wetland areas in dry periods is just below 40, and many wetland areas don't meet the threshold. The mean value for prime farmland areas (many of which are irrigated) was also between 30-40.

Mean grassland "greenness", dry years. Average "greenness" (NDVI*) by catchment for grass, hay, and non-woody vegetation during the driest years since 1984 when Landsat data first became available. Five driest years: 1988 (excluded from average due to large data gaps in Landsat grid), 2001-02, 2006, 2012). Natural cover types only, with developed and cropped lands removed. *Normalized difference vegetation index (NDVI)

[1] The 2016 NLCD was not yet available when we started this project.

is derived from remote sensing data and is an indicator of green vegetation, i.e. biomass. See also NDVI methodology

Mean grassland greenness, wet years. Average "greenness" (NDVI*) by catchment for grass, hay, and non-woody vegetation, for the 4 wettest years. Natural cover types only, with developed and cropped lands removed. 4-year average created from NDVI data for four of the wettest years (1995, 1998, 2010, 2011), four “average” or mid-range years (1992, 1999, 2004, 2017), and four of the driest years (2001-02, 2006, 2012). See also section on NDVI processing.

Mean NDVI variance. Summarized per catchment to show the average NDVI variance, calculated as the square root of the squared difference between each year and the 12-year average year average, as an indicator of variability in grass production. See also section on NDVI processing.

Component Rasters. The following raster layers were used to generate the catchment values above.

Mean Rangeland Productivity. SSURGO soil estimated midrange value for annual potential production of range forage per year (rsprod_r).

Soil Available Water Storage (150 cm weighted average). SSURGO soil weighted average estimate of available water storage in the top 150 cm soil layer (aws0150cm_wta)

Persistence of Mesic Resources Number of years (within the 12 years analyzed) that the July-August NDVI exceeded the mesic threshold value.

Areas with potential for mesic enhancement. Areas that are indicated as potential wetland based on topographic wetness and wet year NDVI, but that become non-mesic during dry years. Legend indicates the number of years out of twelve that the area meets the mesic threshold. Areas meeting the threshold for 6-9 years out of 12 are identified as having the highest potential for enhancement (areas that meet the threshold 10-12 years are considered to be already functioning).

Change from mesic to non-mesic. Areas that change from mesic to non-mesic between wet and dry years. In other words, in wet years, they meet or exceed the mesic threshold value (40) but fall below the threshold during dry years. These areas, particularly if they are riparian, may respond to management practices or restoration designs designed to slow, retain, or store water so that they would meet the mesic threshold even in dry periods.

Departure from ecoregional mean NDVI. Calculated as the difference in NDVI between grid cell 12-year average and 12-year average calculated for that ecoregion, vegetation type, and upland vs riparian landscape position. Positive values represent grid cells that are "greener" than expected while negative values are "less green" than expected. All else being equal, lower values may indicate lower production, stress, or grazing intensity.

Condition Models and Their Components
CATCHMENT POTENTIAL

Catchment potential is comprised of five component indices: Hydrologic intactness, Erosion vulnerability, Soil vulnerability, current stress, and future risk. Each of these is ranked from "Low" to "Highest" based on the component catchment scores, summarized from the component rasters.

Hydrologic intactness represents the potential condition of the landscape at the catchment scale in terms of relatively unmodified landscape hydrology as indicated by connectivity of grassland/perennial land cover. The components of this indicator include percent grass, percent perennial, percent storage, and percent non-riparian (headwater) wetlands at the local catchment scale, as well as cumulative upstream network disturbance. Each of these components was ranked by quartile and summed. The final ranking as "Low", "Med", "High" and "Highest" represents a relative ranking of catchments within the Little Missouri Headwaters project area.

- Percent grass is calculated as the percent of the local catchment that is classified as grasslands, herbaceous wetlands, and/or shrublands
- Percent perennial includes all the categories above as well as woodlands, woody wetlands, and other native or naturalized perennial vegetation classes
- Storage is the total percent wetlands and/or open water at local catchment scale, derived from overlay of NWI with NLCD 2011.
- Non-riparian wetlands represent the upstream percent storage not associated with the active riparian area.
- Network disturbance is the cumulative measure of disturbance (developed or cropped lands) upstream for the local and all upstream catchments, and is derived from the Great Plains Fish Habitat Partnership models conducted by Downstream Strategies.

Erosion vulnerability is a relative indicator of catchment vulnerability to erosion based primarily on slope and soil erodibility. It is composed of four components: mean catchment slope, the proportion of the catchment that exceeds 7% slope, the interaction of soil erodibility (SSURGO kffact) with slope, and the percent of the catchment that is classified as "severe" erosion hazard for roads or trails (including livestock trails). Each of these components was ranked by quartile and summed. The final ranking as "Low", "Med", "High" and "Highest" represents the relative ranking of erosion vulnerability of catchments within the Little Missouri Headwaters project area.

Rasters used to derive the component scores include:

- Slope
- Soil erodibility, i.e. a soil erodibility factor used in models to estimate soil loss by water (Kffact in SSURGO). Low values indicate low vulnerability to erosion, higher values mean higher susceptibility to water erosion from runoff.
- Soil Erosion Hazard is the SSURGO classification of classified as at severe risk of erosion for roads and trails, from the SSURGO Soils Dataset [NRCS/ESRI].

Soil vulnerability is an indicator of the relative hydrologic vulnerability of catchment soils. It is composed of indicators including the percent of the catchment that is classified as "barren" in the NLCD, the percent that has poorly or very poorly drained soils (SSURGO hydrologic soil groups); and the percent of soils that are aridisols

(SSURGO taxonomic order). Each of these components was ranked by quartile and summed to generate a final relative ranking of soil vulnerability as “Low”, “Med”, “High” or “Highest”. Note that most of the areas with “low” vulnerability soils in the landscape are in areas already dominated by agricultural or developed land uses.

Current Stress score Relative ranking of catchment stress based on existing land cover and disturbance such as roads and infrastructure. Composed of the following 8 components, which were ranked by quartile and summed to generate the final relative current stress score:

- Cumulative Anthropogenic Stress Index (CASI). Cumulative Anthropogenic Stress Index (CASI) for four northern prairie fish habitat guilds; derived from the Great Plains Partnership Fish Habitat assessment (conducted by Downstream Strategies). The four relevant northern prairie fish guilds included the Northern headwaters guild, Turbid river species guild, Darter guild, and Madtom guild (GPFHP 2013) The Great Plains FHP assessment by Downstream Strategies focused on characterizing habitat quality and condition for a set of representative fish guilds representative of the Great Plains stream and river habitats. Boosted Regression models were developed for each guild based on local, network, and catchment landscape variables characterizing the natural as well as anthropogenic factors. Boosted Regression models were developed for each guild to predict cumulative natural quality indices (CNQI) and cumulative anthropogenic stress indices (CASI). The Northern headwaters guild model included the following species: brassy minnow (*Hybognathus hankinsoni*), finescale dace (*Phoxinus neogaeus*), pearl dace (*Margariscus margarita*), plains topminnow (*Fundulus sciadicus*). Similar species that would fall within this guild include brook stickleback, plains minnow, silverband shiner, and blacknose shiner. The Turbid river species guild (adapted to life in turbid plains rivers) include plains minnow (*Hybognathus placitus*), shovelnose sturgeon (*Scaphirhynchus platorynchus*), western silvery minnow (*Hybognathus argyritis*), sauger (*Sander canadensis*), flathead chub (*Platygobio gracilis*), shoal chub (*Macrhybopsis hyostoma*), silver chub (*Macrhybopsis storeriana*), sicklefin chub (*Macrhybopsis meeki*), and/or sturgeon chub (*Macrhybopsis gelida*). This guild also includes several SD state SGCN. Although fishes in the darter (incl. Iowa darter, Arkansas darter, johnny darter, orangethroat darter) and madtom (tadpole madtom, freckled madtom, stonecat, slender madtom, Neosho madtom) families are often riffle species associated with clear, perennial, high gradient streams such as those found in the Black Hills, rather than turbid prairie streams, several of these species do occur occasionally in western SD watersheds. The final CASI value was calculated as the average CASI across the four guilds.
- Percent cropland is the percent of catchment classified as cropland under the 2011 NLCD.
- Percent potentially restorable wetlands in ag(riculture). EPA used soils, land use, and other datasets to determine poorly drained soils that are naturally suited to be wetlands but are currently in ag. Range of suitability for restoration from 0-3 with three being high potential for wetland restoration. From the EPA's Enviroatlas mapping website https://www.epa.gov/enviroatlas Accessed 7/16/2017. Metadata: https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/Supplemental/PotentiallyRestorableWetlandsOnAgriculturalLand.pdf
- Percent Developed is the percent of catchment classified as developed (low to high density) under the 2011 NLCD.
- Nitrogen input density (kg/yr/km2), an estimate of anthropogenic nutrient inputs at the local catchment scale for the Great Plains Fish Habitat Partnership Assessment. (GPFHP 2013)i
- Phosphorus input density (kg/yr/km2), an estimate of anthropogenic nutrient inputs at the local catchment scale for the Great Plains Fish Habitat Partnership Assessment.(GPFHP 2013)
- Water well density is the count of water well density per catchment, from county well data obtained separately from the appropriate offices in the respective states.
- Oil and gas infrastructure. Point data of oil and gas wells obtained directly from respective state governments in SD, MT, WY, and ND.

NOTE: We considered incorporating impaired waters listing status based on designated EPA303d TMDL impairments under the national Clean Water Act. For the purposes of this tool, however, we felt this layer provided little additional information for several reasons: nearly all streams above a certain size (based on stream order/drainage area) in this landscape that have been assessed are somewhat impaired for turbidity, sediment, and/or bacteria. Many smaller streams have not been thoroughly assessed. In many cases, the source and origin of impairment is difficult to determine from the existing datasets.

Future Risk score Relative ranking of future risk based on risk of agricultural conversion, oil and gas potential, and wind energy development potential. Composed of the following 3 components, which were ranked by quartile and then summed to generate the final relative future risk score.

- Ag Conversion risk is the catchment mean score for conversion risk. Risk of conversion to cropland agriculture layers were obtained from Jeff Evans of TNC, based on Lipsey et al. (2015)
- Wind potential. Catchment mean score based on wind energy development potential (Fargione et al 2012)
- Oil and Gas Potential. Catchment mean score based on oil and gas development potential (Copeland et al. 2009)

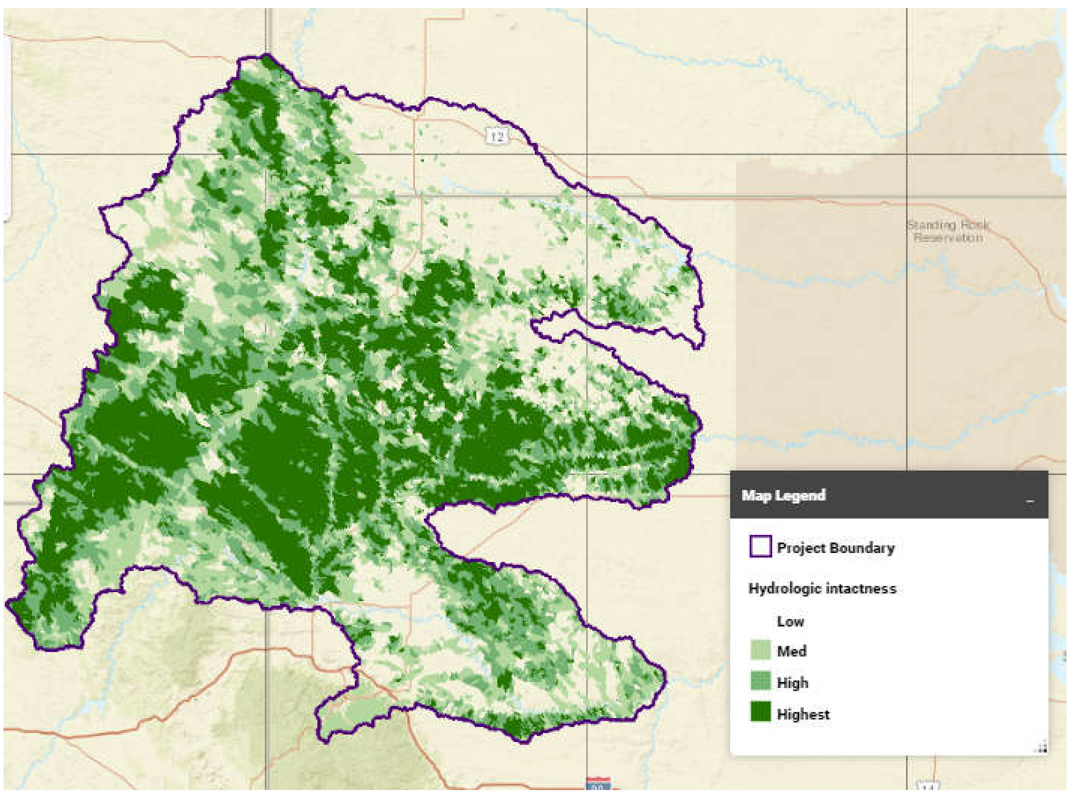


Figure 1. Screen shot from tool of Hydrologic Intactness, Catchment Potential

Condition Models and Their Components
RIPARIAN POTENTIAL

The Riparian potential component includes four component indices: Riparian intactness, erosion vulnerability, and drought vulnerability, and resilience. Riparian area is based on a 100m buffer around all size classes of streams.

Riparian Intactness Relative ranking of intactness of riparian area based primarily on contiguous percentage of grass/perennial land cover with lack of land cover disturbance at the reach scale. This was calculated by generating a raster layer of “disturbance” created from a mosaic of 30m resolution layers (NLCD) indicating developed, cropped, hayed, or otherwise “disturbed” land cover, combined with a 30m raster of roads layers derived from multiple line file sources. Riparian intactness was scored based on the percentage of the riparian area that was disturbed: “Highest” (0), “High” (0-2), “Med” (3-12) to “Low” (>12).

Riparian Resilience Relative ranking of riparian zone resilience based on NDVI (dry versus wet year greenness) and persistence of mesic vegetation (grass cover types only). Areas that maintain mesic conditions during dry periods would rank higher for resilience, while areas with high variance would rank lower.

Riparian Erosion Vulnerability Relative ranking of riparian zone vulnerability to erosion based primarily on topography (stream power and slope) and SSURGO soil characteristics (soil erodibility).

Riparian Drought Vulnerability Relative ranking of riparian vulnerability to drought based on NDVI and SSURGO soil characteristics. This is essentially the inverse of riparian resilience, showing catchments where riparian areas exhibit high variability in vegetation greenness from wet periods to dry periods.

Riparian components

Percent Perennial displays the percent of riparian area classified as perennial vegetation (grass, shrub, woodland, forest, wetland, etc.) (NLCD 2011)

Percent Intact Grassland shows the percent of riparian area classified as perennial non-woody vegetation (grass, shrub, wetland) (NLCD 2011)

Percent Grassland displays the percent of riparian area classified as grassland (grass, herbaceous wetland, hay/pasture) (NLCD 2011)

Percent Wetland displays the percent of riparian area classified as wetlands (wetland, open water, herbaceous and woody wetlands) (NLCD 2011; NWI)

Percent Woodland displays the percent of the riparian area classified as forested or woodland (including shrubland and woody wetland). (NLCD 2011; LANDFIRE Existing Vegetation Type (EVT))

Active River Area (ARA) erodibility index combines Active River Area (ARA), soil erodibility, and stream power index for an index of riparian erodibility.

Riparian component rasters

Riparian woodlands combines ARA and NLCD or LANDFIRE forest or woodland land cover classes

Stream power index is a measure of the potential erosive power of flowing water based on DEM, slope and contributing area

Riparian areas with potential for mesic enhancement Areas in the active riparian zone that are potentially mesic based on topographic wetness and wet year NDVI, but that become non-mesic during dry years. Legend indicates the number of years out of twelve that the area meets the mesic threshold. Areas meeting the threshold for 6-9 years out of 12 are identified as having the highest potential for enhancement.

ARA potential wet areas Riparian areas that are modeled as potential wetland habitat based on wetness index and NDVI; derived based on overlay of ARA, NDVI, and EPA potential wetness modeled from topographic wetness index analysis (EPA EnviroAtlas)

Riparian Valley Bottom is a refinement of the Active Riparian Area developed using ArcMap hydro and topographic modeling tools to identify the valley bottoms, modeled after Gilbert et al. (2016). For additional info, see section on Active Riparian Area.

Active Riparian Area Represents the maximum potential extent of active riparian and floodplain area function and processes; derived based on topographic and terrain analysis using a 10m DEM. For additional info, see section on Active Riparian Area.

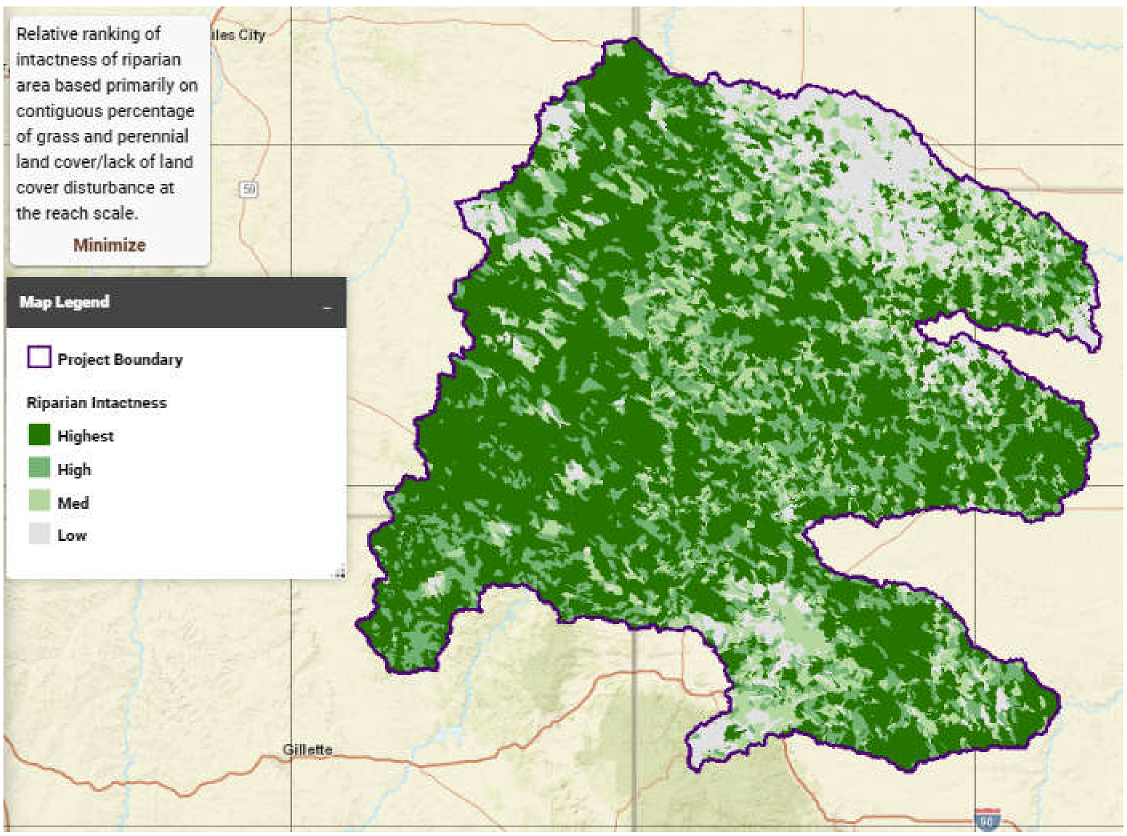


Figure 2. Screen shot from tool of Riparian Intactness, Riparian Potential.

Explorer Modules and Their Components
BIODIVERSITY

Select biodiversity layers representing indicators of grassland health, condition, and connectivity.

Grassland Birds importance. The five grassland bird species selected as focal species for modeling in the 2016 Northern Great Plains business plan were Baird's Sparrow, Chestnut-collared Longspur, Lark Bunting, McCown's Longspur, and Sprague's Pipit (NFWF 2016; after Correll et al. 2016).

Grassland Birds focal species richness is an index of species richness based on overlay of the 5 focal grassland species (NFWF 2016; after Correll et al. 2016).

Sage grouse habitat importance Sage grouse core habitat scaled from 0-3 (with 3=highest importance) based on multiple sage grouse studies and plans (SGI and state data sources).

Plant Species of Greatest Conservation Need (SGCN) Count of plant Element Occurrences (EOs), derived by overlaying NHD catchments with respective state Natural Heritage geodatabases maintained per NatureServe standards.

Animal SGCN Count of animal Element Occurrences (EOs), derived by overlaying NHD catchments with respective state Natural Heritage geodatabases maintained per NatureServe standards.

Aquatic SGCN Count of fish/aquatic Element Occurrences (EOs), derived from respective state Natural Heritage geodatabases maintained per NatureServe standards.

Overlapping Conservation Priority Areas Count of overlapping priority areas including TNC, sage grouse plans, and state wildlife action plan conservation opportunity areas

Great Plains Fish Habitat Partnership protection opportunity Prairie fish protection priority based on Great Plains Fish Habitat Partnership models for turbid river and northern headwater species guilds.

Explorer Modules and Their Components

MANAGEMENT AND RESTORATION

Ownership and management information as well as some preliminary recommendations for collaborative conservation opportunities and next steps based on combinations of condition and potential.

Stock Water Features The stock water feature layer was created by The Nature Conservancy with volunteer labor and public data sources to visually digitize stock dams and other modified water features detectable from aerial imagery at ~1:7000 scale.

Surface Ownership and Management

Public and NGO land. Shows ownership / management of surface land by primary surface management agency. Derived from the Protected Areas Dataset of the United States (PADUS), produced by USGS GAP analysis program and obtained in 2016.

Percent public ownership by catchment. Displays percent public ownership / management of surface land; derived by overlay of NHD catchment with PADUS dataset above.

Management Opportunities

Coordinated planning: mixed public ownership Intact grassland catchments with significant mix of public ownership by multiple agencies.

Improve riparian mesic habitat Intact grassland catchments showing overall vulnerability in dry years but with opportunity to restore or enhance riparian mesic habitat along significant portions of the riparian corridor

Address riparian erosion vulnerability Intact grassland catchments showing low vulnerability to erosion at catchment scale but high riparian erosion vulnerability, indicating relatively higher potential for success of site-level efforts.

Intact grassland with high grassland bird value Intact grassland catchments showing high significance for sage grouse and/or grassland bird focal species

Intact grassland with good aquatic habitat potential Intact grassland catchments scoring high on protection value and natural quality index for representative prairie stream fish guilds (GPFHP 2013)

Seek improved understanding of rangeland condition Intact grassland catchments with lower-than-expected rangeland NDVI based on ecoregion and landscape position.

Component rasters

Stream power index A measure of the potential erosive power of flowing water based on DEM, slope and contributing area. (See more detailed description under Definitions and Acronyms.)

Areas that are mesic except in dry years Areas that meet the greenness threshold for mesic habitats in all but the driest years. (See also Methodology for NDVI processing)

ARA potential wet areas. Areas with the Active Riparian Area that have wetland potential based on overlay of wetness index and NDVI values. (See also Methodology for NDVI processing)

Rangeland below ecoregional average NDVI Difference in NDVI between grid cell 12-year average and 12-year average calculated for that ecoregion, vegetation type, and upland vs riparian landscape position. Positive values represent grid cells that are "greener" than expected while negative values are "less green" than expected. All else being equal, lower values may indicate lower production, stress, or grazing intensity. (See also methodology for NDVI processing)

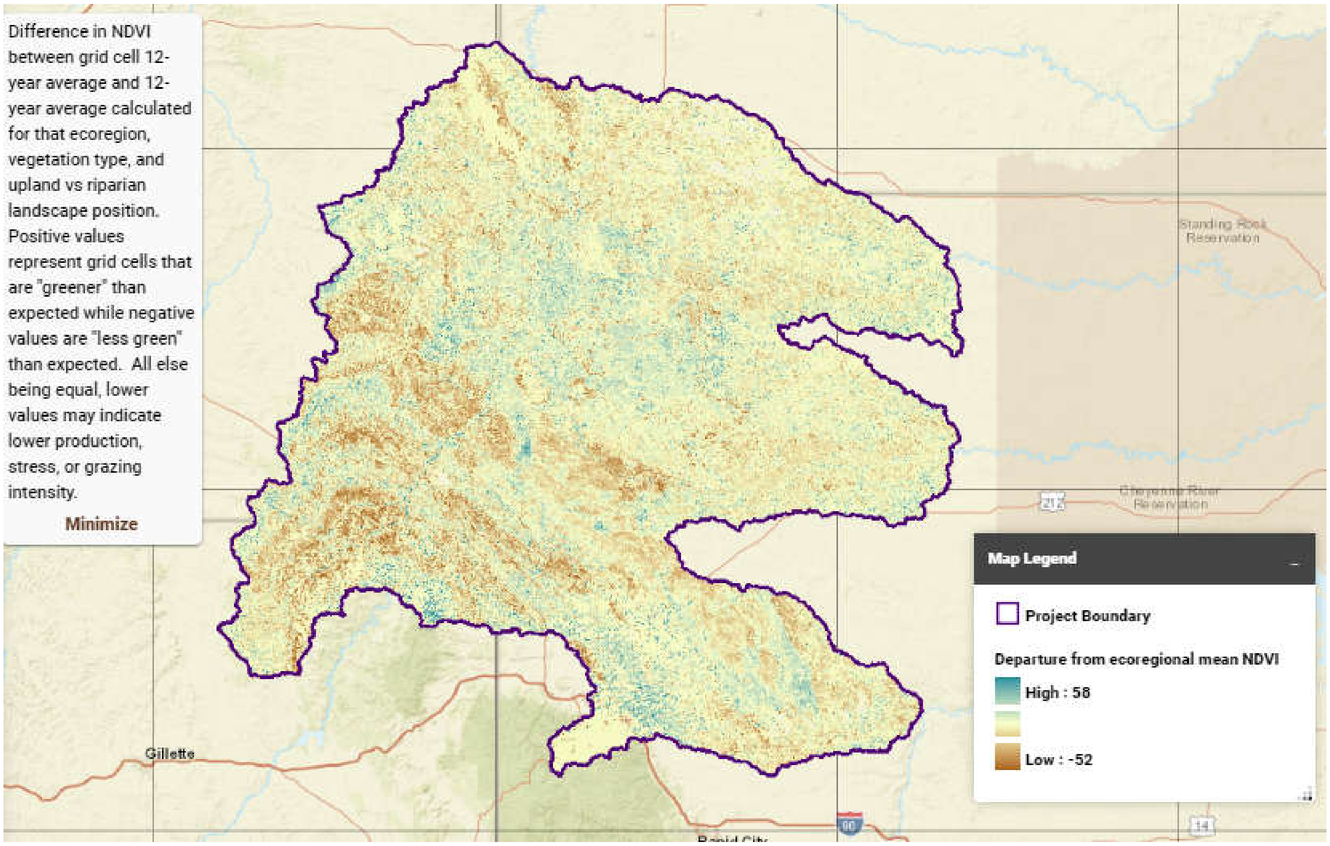


Figure 3. Screen shot from tool of component raster, “Rangeland below ecoregional average NDVI”, under Management and Restoration menu.

Component Layers

This section describes the methodologies used to derive component layers used to generate layers for the Riparian and Rangeland tool, where not obtained directly from other sources. For methodology used to derive layers obtained directly from other sources, see References.

Active Riparian Area (ARA)

The Active River Area conservation framework is designed to provide a conceptual and spatially explicit basis for the assessment, protection, management, and restoration of freshwater and riparian ecosystems (Smith et al. 2008). The active river area framework is based upon dominant processes and disturbance regimes to identify areas within which important physical and ecological processes of the river or stream occur. The framework identifies five key subcomponents of the active river area: 1) material contribution zones, 2) meander belts, 3) riparian wetlands, 4) floodplains and 5) terraces. These areas are defined by the major physical and ecological processes associated and explained in the context of the continuum from the upper, mid and lower watershed in the ARA framework paper (Smith et al. 2008). The framework provides a spatially explicit manner for accommodating the natural ranges of variability to system hydrology, sediment transport, processing and transport of organic materials, and key biotic interactions.

Topographic analysis in ArcMap using GIS techniques developed by The Nature Conservancy's Eastern Freshwater Program allow the riparian active river area components to be identified over a range of spatial scales. The toolbox allows the riparian component of the Active River Area to be mapped at the regional scale, using a 30m DEM and 1:24,000 and/or 1:100,000 hydrography. The non-riparian Active River Area component (i.e. the headwater watershed material contribution zone), is not readily mapped regionally at this time.

The Riparian Active River Area model delineates an ARA Riparian Base Zone using cost distance modeling and an additional ARA Riparian Material Contribution Zone extending three 30m cells (90-125m total) on either side of input water cells for those streams and rivers. Meander belts, riparian wetlands and wetflats, 100-500 year floodplains, and lower terraces can all be expected to fall primarily within the ARA Riparian Base Zone. It is on these landforms that we expect water is most likely to accumulate and create mesic habitat under average climate conditions.

The ARA may also include additional near stream/river habitat that is at higher slope than the base zone, representing the "material contribution zone". This may include older, rarely active terraces and is generally less subject to overbank flows and direct hydrologic connection to the stream/rivers. However, this area contributes to other important riverine processes such as shading, input of woody debris, sediments, and nutrients which influence river health, and also provides habitat to certain species more closely associated with near shore or riparian ecosystems.

The Active River area maps and conceptual framework can be used to inform management efforts such as conservation planning, the establishment of protected area networks, the development and implementation of management policies and programs, and river restoration projects. Protection of the active river area provides benefits to aquatic and terrestrial species that rely on instream, riparian and floodplain habitat to carry out their life cycles. An intact active river area also offers a wide range of benefits to society including the reduction of flood and erosion hazards, protecting water quality, and providing the many subsistence, commercial, recreational and economic benefits associated with healthy freshwater systems.

Methodology for Processing and Analyzing NDVI data

The **normalized difference vegetation index** (**NDVI**), conceptually, is a simple graphical indicator derived from the spectral signature of the landscape as detected via remote sensing measurements for "greenness", used to assess whether the target being observed contains live green vegetation or not. The NDVI remains the most well-known and used index to detect live green plant canopies in multispectral remote sensing data, and is regarded as one the most successful of many attempts to simply and quickly identify vegetated areas and their "condition." Robinson and colleagues (2017) produced a Landsat derived, high resolution (30 m), long-term (30+ years) NDVI dataset for the conterminous United States that attempts to reconcile the limitations of readily available but coarse-scale NDVI products with less readily available but higher resolution NDVI datasets, using Google Earth Engine, a planetary-scale cloud-based geospatial analysis platform, to process Landsat data and distribute the final dataset. They used a climatology driven approach to fill missing data and validate the dataset with established remote sensing products at multiple scales, and provide access to the composites through a simple web application, allowing users to customize key parameters appropriate for their application, question, and region of interest.

NDVI data for this project were downloaded from the University of Montana web server at https://ndvi.ntsg.umt.edu/ from Robinson et al. (2017). Data were downloaded as two 16-day averages for each year based on a late summer period of dates that represent a seasonal period of water stress, i.e. ~July 28 to ~August 28. Data were averaged to produce a grid for each of the 5 wettest years and 5 driest years of the years since Landsat was launched in 1984. The five wettest and 5 driest years were determined from climate data for the region obtained from NOAA https://www.ncdc.noaa.gov/cag/time-series/us/105/0/pcp/ytd/12/1895-2017?base_prd=true&firstbaseyear=1901&lastbaseyear=2000 .

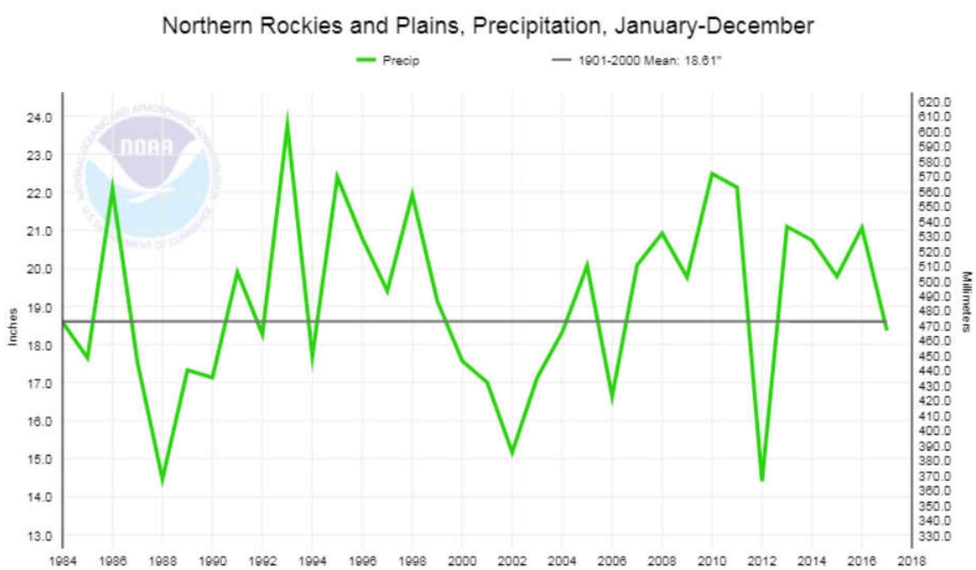


Figure 4. Average years: 1985, 1992, 1994, (all slightly below average), 1997 (slightly above), followed by 1989-1990 (below), 2009 (above), 2015 (above) and 2005/7 (above)

The wettest years in order of wetness were: 1993, 2010, 1995, 2011, and 1998. The driest years were 2012, 1988, 2002, 2006, and 2001. Both categories had one year with large data gaps due to cloud cover, so wet and dry period NDVI grids were produced using 4-year averages.

Analysis of the NDVI to develop indicators of vegetation production (or "greenness")

Determination of Mesic Habitats based on the NDVI. "Mesic" habitat refers to land with a well-balanced supply of moisture throughout the growing season, such as streamsides, wet meadows, springs and seeps, irrigated fields and high-elevation habitats. Where land is in native vegetation, it is an indicator of the more productive riparian habitats, i.e. those habitats upon which so much grassland wildlife and livestock are dependent, especially during dry periods. The selection of an NDVI threshold value of 40 for mesic conditions is based on an approach developed for the Sage Grouse Initiative in the Colorado Gunnison sage grouse area as well as the value used for mesic habitats in the SGI tool (Chapman, pers. comm; see section on Sage Grouse Initiative tool). For the Little Missouri Headwaters region, it represents a relatively median value for the NDVI. During wet years, the threshold value of 40 for wetlands is greater than the mean across the study, but the mean value for wetland areas in dry periods is just below 40, and many wetland areas don't meet the threshold. The mean value for prime farmland areas (many of which are irrigated) was also between 30-40.

Raster layers derived from the NDVI

Persistence of Mesic Resources Number of years (within the 12 years analyzed) that the July-August NDVI exceeded the mesic threshold value.

Areas with potential for mesic enhancement. Areas that are indicated as potential wetland based on topographic wetness and wet year NDVI, but that become non-mesic during dry years. Legend indicates the number of years out of twelve that the area meets the mesic threshold. Areas meeting the threshold for 6-9 years out of 12 are identified as having the highest potential for enhancement (areas that meet the threshold 10-12 years are considered to be already functioning).

Change from mesic to non-mesic. Areas that change from mesic to non-mesic between wet and dry years. In other words, in wet years, they meet or exceed the mesic threshold value (40) but fall below the threshold during dry years. These areas, particularly if they are riparian, may respond to management practices or restoration designs designed to slow, retain, or store water so that they would meet the mesic threshold even in dry periods.

Departure from ecoregional mean NDVI. Calculated as the difference in NDVI between grid cell 12-year average and 12-year average calculated for that ecoregion, vegetation type, and upland vs riparian landscape position. Positive values represent grid cells that are "greener" than expected while negative values are "less green" than expected. All else being equal, lower values may indicate lower production, stress, or grazing intensity.

Dry year NDVI. 4-year average NDVI for the driest years since 1984 when Landsat data first became available. Driest years: 2001-02, 2006, 2012). 1988 (excluded from average due to large data gaps in Landsat grid). Natural cover types only, with developed and cropped lands removed.

Wet year NDVI. 4-year average NDVI for the wettest years since 1984 when Landsat data first became available. Natural cover types only, with developed and cropped lands removed. 4-year average created from NDVI data for four of the wettest years (1995, 1998, 2010, 2011).

12 year NDVI. Average NDVI for the four "average" or mid-range years (1992, 1999, 2004, 2017), the four driest, and four wettest years. Natural cover types only, with developed and cropped lands removed.

Stock Water Features
Layer Description

This layer was created by staff and volunteers on behalf of The Nature Conservancy in MN, ND, and SD. It is designed to show the scale of potential hydrologic modification of the landscape in the Little Missouri/Slim Buttes study area in SD/ND/WY/MT. The focus was on identifying stock watering features. Digitized features include: 1) Reservoirs, 2) Dugouts, 3) Wells/windmills/stock water tanks, 4) Other features such as irrigation canals or water spreading dikes, 5) Breached reservoirs.

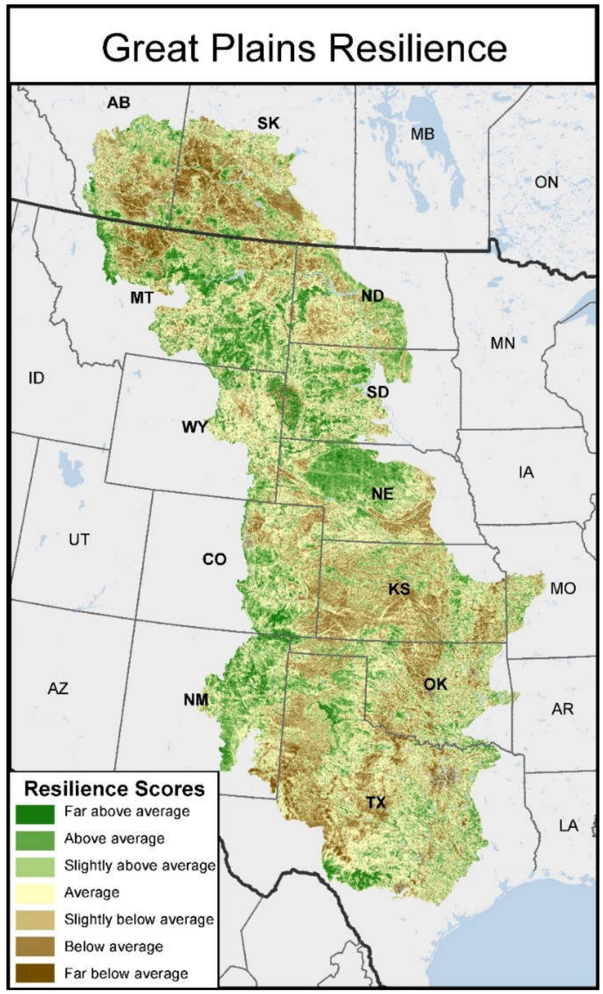
Features were identified using current aerial photography viewed at a 1:7,000 scale, allowing features to be identified one quarter section at a time. All land ownerships were interpreted. Note that no field verification of this has been done. As of 2018/07, data coverage included all of Harding County, SD and portions of the following counties: Bowman County, ND; Butte County, SD; Carter County, MT; Lawrence County, SD; Meade County SD, Slope County, ND.

Valley Bottom
Layer Description

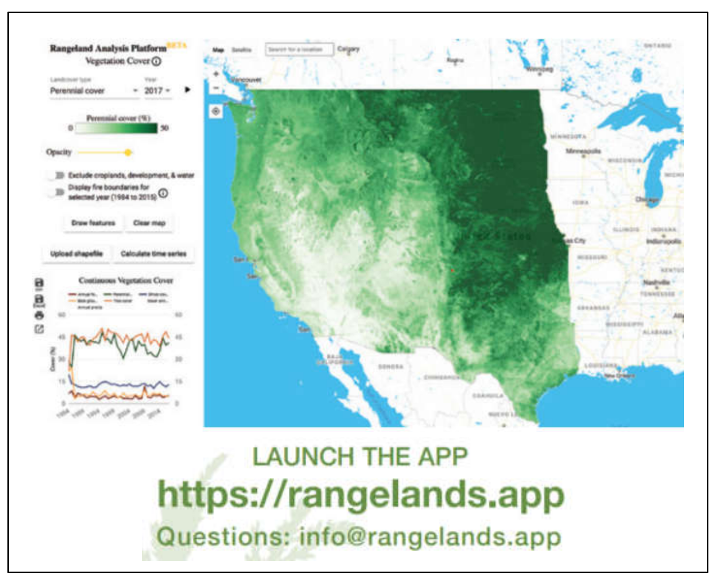
This layer was created for this project by The Nature Conservancy in MN, ND, SD as a refinement of the Active Riparian Area. Valley bottoms were developed using ArcMap hydro and topographic modeling tools (a DEM, a flow accumulation model, and a stream network file) to identify the valley bottoms, modeled after Gilbert et al. (2016; https://bitbucket.org/jtgilbert/riparian-condition-assessment-tools/wiki/Home). The maximum extent of the valley bottom for small, medium, and large size class streams was constrained to a 25m, 50m, and 100m buffer and 2.5, 3.5, and 6 degree slope threshold respectively.

Additional Sources of Information and Companion Tools for Grassland Conservation Planning

Resilient Sites for Terrestrial Conservation in the Great Plains. In 2018, The Nature Conservancy, working with partners from eleven states and two countries, completed and released a large multi-year study to identify and map the climate-resilient sites that could sustain the important features in the Great Plains region. Situated in the center of the US, the Great Plains support 10% of the world's grasslands and the largest remaining herds of native grazing mammals like bison and pronghorn. The prairies, sandhills, and wetlands vary across the landscape in response to a strong west-to-east precipitation gradient caused by the rain shadow of the Rocky Mountains to the west, and locally by variation in landforms and geology. Fire, drought, and grazing have played key roles in shaping the prairies, and their size and connectivity are important indicators of their viability. In most of the Great Plains' ecoregions, over 90% of the land is in private ownership, but compatible land use practices such as sustainable ranching practices play important roles in supporting ecosystem function and diversity. A report explaining the methods, datasets for download, and interactive web tools to explore the results and measure the resilience of places can be accessed from The Nature Conservancy weblink: http://nature.org/GPResilience.



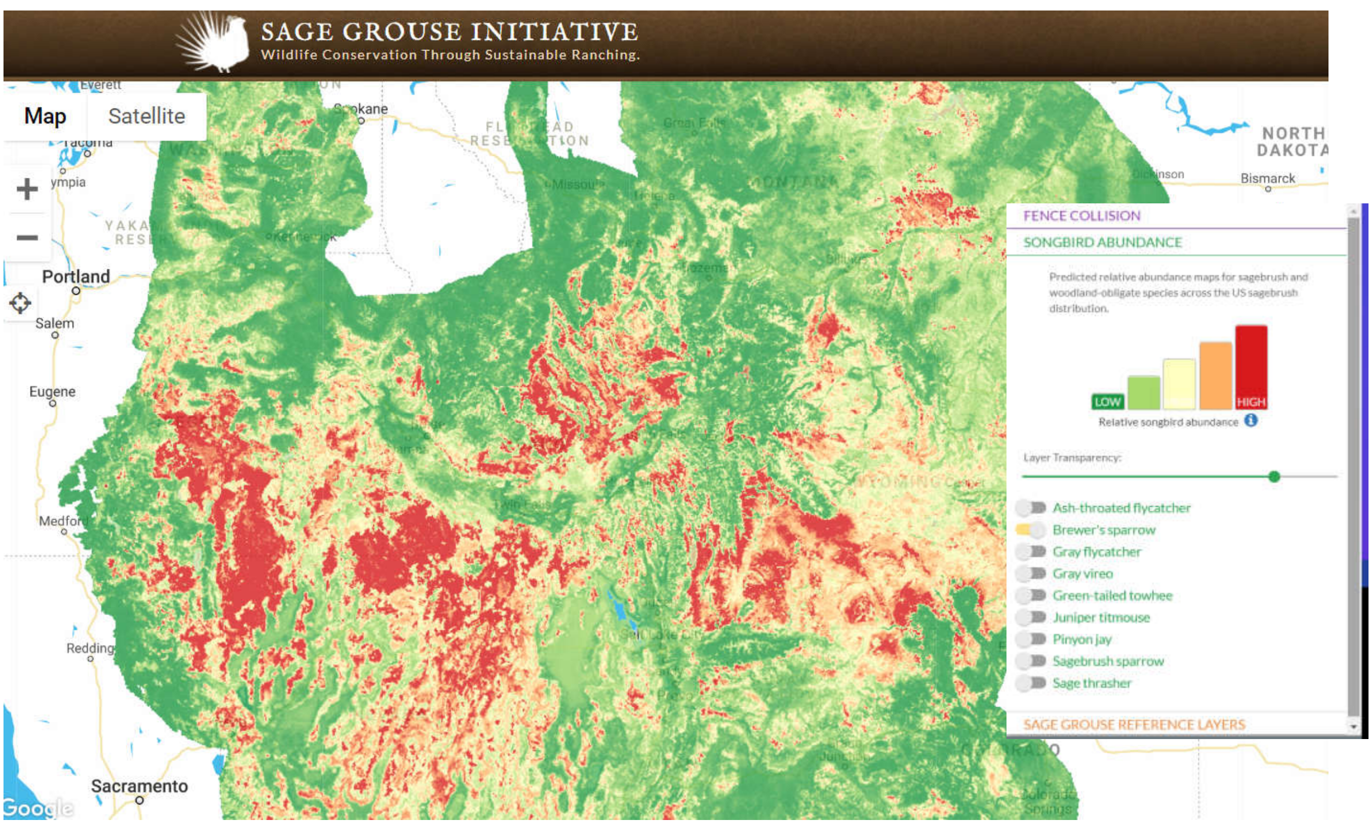
Rangeland Analysis Platform: Revolutionizing Rangeland Monitoring. This free, publicly available tool shows rangeland resources from America's Great Plains to the Pacific Ocean. Built for landowners, managers, and conservationists to empower them to track vegetation through time, the platform equips people with the information needed to improve America's grazing lands. Developed by the University of Montana in collaboration with the USDA's Natural Resources Conservation Service and the Department of Interior's Bureau of Land Management, powered by Google Earth Engine, RAP merges machine learning and cloud-based



computing with remote sensing and field data to provide the first-ever annual vegetation cover maps of rangeland vegetation on U.S. grazing lands. This easy-to-use mapping technology allows people to view trends in rangeland resources through an unprecedented blend of space (from the Great Plains to the Pacific Ocean), time (1984 to present) and scale (at the ranch, county, or watershed level). Designed to be combined with local knowledge, RAP can help users analyze the outcomes of land management actions. For instance, it can help visualize the impacts of drought on perennial forage, identify where to reduce woody encroachment, or evaluate the effectiveness of weed control treatments, to help users improve rangeland productivity and sustainability over time. https://rangelands.app/

Sage Grouse Initiative. The Sage Grouse Initiative is a partnership-based, science-driven effort that uses voluntary incentives to proactively conserve America's western rangelands, wildlife, and rural way of life. This initiative is part of Working Lands For Wildlife, led by the USDA Natural Resources Conservation Service. https://www.sagegrouseinitiative.com/

The NRCS-funded Sage Grouse Initiative also has developed a web map application for interactively visualizing and displaying spatial data produced by the SGI's science team for the sage-brush steppe region of the western United States, a region that extends over a portion of the Little Missouri Headwaters. The tool provides Ecosystem and Wildlife mapping components, including a mapping approach to identifying Mesic Resources that provides information similar to our analysis of NDVI. Descriptions and instructions, as well as tools for downloading the data, are provided at https://map.sagegrouseinitiative.com/wildlife/songbird-abundance?ll=43.4799,-110.7624&overlay=brsp&opacity=0.80&z=6&basemap=roadmap



Definitions and Acronyms - Alphabetically

Active Riparian Area (ARA) represents a conservative potential "footprint" of active riparian and floodplain area function and processes; derived based on topographic and terrain analysis using a 10m DEM. For additional info, see Methodology section on Active Riparian Area.

Aridisol refers to soil taxonomic orders that are relatively more vulnerable to salinity and/or drought.

Cumulative Anthropogenic Stress Index (CASI). Generically CASI is an index of human-caused stressors to or alterations of fish habitat derived based on multivariate analysis using boosted regression tree modeling of fish response, as described in the Great Plains FHP assessment by Downstream Strategies (GPFHP 2013).

Element Occurrence (EO). An Element Occurrence (EO) is an area of land and/or water in which a species or natural community is, or was, present. An EO should have practical conservation value for the **Element** as evidenced by potential continued (or historical) presence and/or regular recurrence at a given location. http://help.natureserve.org/biotics/Content/Record_Management/Element_Occurrence/EO_Element_Occurrence.htm

gSSURGO – gridded Soil Survey Geographic Data. See SSURGO definition, below.

Major Land Resource Areas (MLRA). are geographically associated land resource units delineated by the Natural Resources Conservation Service and characterized by a particular pattern that combines soils, water, climate, vegetation, land use, and type of farming. See General Physical and Ecological Info**.**

Mesic habitat refers to land with a well-balanced supply of moisture throughout the growing season, such as streamsides, wet meadows, springs and seeps, irrigated fields and high-elevation habitats. https://www.sagegrouseinitiative.com/mesic/

Normalized Difference Vegetation Index (NDVI) See methodology section on NDVI analysis

National Hydrography Dataset (NHD) is a package of digital geospatial datasets that represent the nation's drainage networks and related features, including rivers, streams, canals, lakes, ponds, glaciers, coastlines, dams, and streamgages. The **NHD**, at 1:24,000 scale or better, is the most up-to-date and detailed hydrography dataset for the Nation. https://www.usgs.gov/core-science-systems/ngp/national-hydrography

National Land Cover Dataset (NLCD) is a comprehensive land cover product, derived from decadal Landsat satellite imagery and other supplementary datasets. The NLCD is created and maintained through the Multi-Resolution Land Characteristics (MRLC) consortium, a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications. We used the 2011 data product for this tool as the 2016 product was not released when we started https://www.mrlc.gov/

Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS), is an agency of the United States Department of Agriculture that provides America's farmers and ranchers with financial and technical assistance to voluntarily put conservation on the ground. www.nrcs.usda.gov

National Wetlands Inventory (NWI) is a publicly available resource that provides detailed information on the abundance, characteristics, and distribution of US wetlands. NWI data are used by natural resource managers, within the US FWS and throughout the Nation*,* to promote the understanding, conservation and restoration of wetlands. www.fws.gov.wetlands/*.*

SSURGO (Soil Survey Geographic Data) refers to digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC). The database has information on soil types and their distribution, covering soil characteristics, soil properties, and addressing limits, risks and suitability for various uses. NRCS distributes soil survey data online through the Web Soil Survey and Soil Data Viewer URLs. ESRI also provides quick access to ready-to-use map packages, through a web mapping interface organized at the Huc8 scale, filled with useful soil data derived from the SSURGO dataset. https://esri.maps.arcgis.com/apps/View/index.html?

SGCN, Species of Greatest Conservation Need (SGCN) The federal State Wildlife Grants program provides funds for conservation efforts aimed at preventing fish and wildlife populations from declining, reducing the potential for these species to be listed as endangered. To access these grant funds, states are required to develop a Comprehensive Wildlife Conservation Strategy (CWCS) that focuses on the Species of Greatest Conservation Need (SGCN). SD, ND, WY, and MT all track SGCN through their respective state wildlife action plans.

SPI, Stream Power Index is a measure of the potential erosive power of flowing water based on DEM, slope and contributing area. It is calculated as SPIi = ln(DAi * tan(Gi)) where SPI is the stream power index at gridcell i, DA is the upstream drainage area (flow accumulation at gridcell i multiplied by gridcell area), and G is the slope at a grid cell.

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[1] Water Quality and TMDLs

We considered including a layer in the tool showing 303d/TMDL listed streams. However, ultimately we decided not to include this layer and to use estimated nutrient loading from previous assessments instead. This was because the majority of streams over a certain size threshold in this region are designated impaired for turbidity or bacteria, but the existing data layers do not make it simple to tease out sources or specific causes of impairment

References

Anderson, M.G., M.A. Ahlering, M. M. Clark, K.R. Hall, A. Olivero Sheldon, J. Platt and J. Prince. 2018. Resilient Sites for Terrestrial Conservation in the Great Plains. The Nature Conservancy, Eastern Conservation Science and North America Region.

Copeland, H. E., Doherty, K. E., Naugle, D. E. Pocewicz, A., & Kiesecker, J. M. (2009). Mapping oil and gas development potential in the US Intermountain West and estimating impacts to species. *PLOSOne*, 4(10), e7400. https://doi.org/10.1371/journal.pone.0007400

Correll, M.D., N. Drilling, A. Dwyer, T. L. George, A. W. Green, A. O. Panjabi, D. C. Pavlacky Jr, L. Quattrini, A. Shaw, R. A. Sparks, E. H. Strasser, A. Van Boer. 2016. Recommendations for grassland bird species conservation in the Northern Great Plains (NGP) business plan. Final report. Bird Conservancy of the Rockies, Brighton, Colorado, USA

Fargione, J., Kiesecker, J., Slaats, M. J., & Olimb, S. (2012). Wind and wildlife in the Northern Great Plains: Identifying low-impact areas for wind development. *PLoS ONE*, *7*(7). https://doi.org/10.1371/journal.pone.0041468

Gage, A. M., Olimb, S. K., & Nelson, J. (2016). Plowprint: Tracking Cumulative Cropland Expansion to Target Grassland Conservation.

Gilbert JT, Macfarlane WW, Wheaton JM (2016) V-BET: a GIS tool for delineating valley bottoms across entire drainage networks Comput Geosci 97:1-14

Great Plains Fish Habitat Partnership (GPFHP). 2013. Great Plains Fish Habitat Partnership Fish Modeling Results. Downstream Strategies. 2013-05-10(creation), 2017-08-30 (Update), Plains and Prairie Potholes Landscape Conservation Cooperative (administrator). [Accessed 9/1/2017] https://www.sciencebase.gov/catalog/item/5a203a85e4b09fc93ddbad41

LANDFIRE: LANDFIRE Existing Vegetation Type layer (2013, June - last update). U.S. Department of Interior, Geological Survey. [Online]. Available: http://landfire.cr.usgs.gov/viewer/ [Accessed 2/20/2018].

LANDFIRE: LANDFIRE Biophysical Settings Potential layer. (2013, June - last update). U.S. Department of Interior, Geological Survey. [Online]. Available: http://landfire.cr.usgs.gov/viewer/ [Accessed 3/16/2018].

Lipsey, M.K., Doherty, K., Naugle, D.E., Fields, S., Evans, J.S., Davis, S.K., Koper, N., 2015. One step ahead of the plow: using cropland conversion risk to guide Sprague's pipit conservation in the northern Great Plains. Biological Conservation 191, 739-749.

National Fish and Wildlife Foundation (NFWF; 2016). *Business Plan for the Northern Great Plains.* URL: www.nfwf.org

NRCS/ESRI. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Accessed via the ESRI SSURGO Downloader: ready-to-use map packages with over 150 attributes derived from the SSURGO dataset. Web Mapping Application by Esri. https://esri.maps.arcgis.com/apps/View/index.html? [Accessed 7/17/2017 – 2/1/2018.]

NRCS. (2017). Mesic Habitat Conservation Planning Guide.

Omernik, J.M. and G.E. Griffith. 2014. Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. *Environmental Management* 54(6):1249-1266.

Park, J. Y., Ale, S., Teague, W. R., & Dowhower, S. L. (2017). Simulating hydrologic responses to alternate grazing management practices at the ranch and watershed scales. *Journal of Soil and Water Conservation*, *72*(2), 102–121. https://doi.org/10.2489/jswc.72.2.102

Pérez, M. (2017). *Restoration/Resilience-building of riparian and wet meadow habitats, Upper Gunnison River Basin, Colorado. Final Report to the Terra Foundation*. https://doi.org/10.1002/ejoc.201200111

Pellant, M., Shaver, P., Pyke, D. A., & Herrick, J. E. (2014). *Interpreting Indicators of Rangeland Health. BLM*. https://doi.org/10.1007/s13398-014-0173-7.2

Perry, L. G., Reynolds, L. V., Beechie, T. J., Collins, M. J., & Shafroth, P. B. (2015). Incorporating climate change projections into riparian restoration planning and design. *Ecohydrology*, *8*(5), 863–879. https://doi.org/10.1002/eco.1645

Robinson, N.P., B.W. Allred, M.O. Jones, A. Moreno, J.S. Kimball, D.E. Naugle, T.A. Erickson, and A.D. Richardson. 2017. A Dynamic Landsat Derived Normalized Difference Vegetation Index (NDVI) Product for the Conterminous United States. *Remote Sensing* 9:863.

Robinson, N.P.; Allred, B.W.; Jones, M.O.; Moreno, A.; Kimball, J.S.; Naugle, D.E.; Erickson, T.A.; Richardson, A.D. A Dynamic Landsat Derived Normalized Difference Vegetation Index (NDVI) Product for the Conterminous United States. *Remote Sens.* **2017**, *9*, 863.

Sedivec, K.K. and J.L. Printz. (2014). Ranchers Guide to Grassland Management. NDSU Extension Service, Fargo, ND.

Silverman, N. L., Allred, B. W., Donnelly, J. P., Chapman, T. B., Maestas, J. D., Wheaton, J. M., … Naugle, D. E. (2018). Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. *Restoration Ecology*. https://doi.org/10.1111/rec.12869

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. Agricultural Handbook 296 digital maps and attributes. Available online. Accessed [7/17/2017]. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053624

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online. Accessed [6/15/2017]. (via NRCS/ESRI SSURGO Downloader app)

Sweikert, L. A. (2017). Human Dimensions of Habitat Loss in the Plains and Prairie Potholes Ecoregion. M.S. Thesis. South Dakota State University.

U.S. Environmental Protection Agency. EnviroAtlas. Potentially Restorable Wetland Areas on Agricultural Land and Potential Wetland Areas. https://enviroatlas.epa.gov/enviroatlas [Accessed 7/6/2017].

U.S. Environmental Protection Agency. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

U. S. Fish and Wildlife Service. Publication date (found in metadata). National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.gov/wetlands/

U.S. Geological Survey. 2002-2016. National Hydrography Dataset and tabular data. Reston, Virginia. https://www.usgs.gov/core-science-systems/ngp/national-hydrography