

A Spatially Explicit and Quantitative Vulnerability Assessment of Coldwater Fish Habitat and Riparian Corridors in the Intermountain West

Appendix 3 of the Final Report: Description of Indicators used in the Final Assessment

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Below we provide a detailed description of indicators used to measure exposure, sensitivity, and adaptive capacity for coldwater fish habitat and riparian corridors in the Four Corners and Upper Rio Grande regions of the Southern Rockies LCC. We developed this final set of indicators using feedback on an initial set presented at the 2017 SRLCC Adaptation Forums (https://southernrockieslcc.org/geographical_area/four-corners-region). Results from the final assessment are presented in the main body of this report.

Coldwater Fish Exposure

1. Change in flow volume of temperature 2040

Source: US Forest Service Western US Stream Flow Metric Dataset, U.S. Forest Service NORWEST stream temperature projections

Description: Differences between projections of mean annual cumulative streamflows, mean daily streamflows, and mean August water temperatures for historical and future periods, used as an indicator of future change in habitat suitability

Justification: Perennial flows are required by all fish species. Peak flows induce reproductive behavior of many fishes, provide instream habitat for spawning, and facilitate reproduction and survival of riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002). In addition, stream temperatures influence spawning behavior, reproductive success, and adult survival of native fish (McCullough 1999, Pankhurst and Munday 2011).

Data compilation: We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC model was used to translate climate data into streamflow (USFS 2015).

We also obtained data from the NORWEST spatial statistical stream network website (<https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/ModeledStreamTemperatureScena>

rioMaps.shtml). NORWEST models were used to apply mean August water temperature to stream reaches. Models contained 12 variables. Two variables (air temp and stream discharge) were calculated at the scale of basin. An additional 10 variables were calculated at the scale of reaches or catchments. Climate projections included A1B emissions scenarios applied to 10 GCMs selected because of low bias across the region. A relationship of changes in air temperature to changes in stream temperature was applied across each basin and an adjustment was made for each segment, reflecting the observation that cooler stream warm more slowly than warm streams.

For stream volume, we calculated the difference between projections for the historical period of 1977-2006 and the future period of 2030-2059. For stream temperature, we compared projections between the recent period of 1993 to 2001 and the future period of 2030-2059. We gave each HUC 12 a score of 1 if at least one of the following occurred at stream segments within the watershed: (a) the difference between historical projections and future projections of mean annual flow is ≥ 1 cfs; (b) the difference between historical projections and future projections of mean summer flow is ≥ 1 cfs; (c) projected water temperatures for a stream segment are within the temperature range of ideal trout habitat during the recent period (9-11° C), but are too warm during the future period ($> 11^\circ$ C).

Uncertainties: Only one emissions scenario (A1B) was used for projections. The 10 GCMs were selected because they showed the lowest bias across the region of interest. For temperature projections, Modelers did not predict changes for individual reaches, but applied a uniform percent increase to each basin. In addition, mean August stream temperature may not be as critical to salmonids as stream temperatures in June or July, which is typically the hottest and driest period in the southwest.

2. Road crossings density

Source: U.S. Census Bureau, National Hydrography Dataset

Description: Density of points where roads (2010 Census Tiger Lines) cross perennial streams within watersheds

Justification: Road crossings can function as dispersal barriers to native fish and can degrade water quality through introduction of sediment (DRACU 2016).

Data compilation: We downloaded data from the NHDplus website (<http://www.horizon-systems.com/nhdplus/>) and the UCB TIGER/Line site (<https://www.census.gov/geo/maps-data/data/tiger-line.html>). We intersected a shapefile containing all road types with a shapefile of perennial streams to create a layer of road crossing points. We calculated the number of crossings per km² for each HUC12 watershed. If density of road crossings is $\geq 0.1/\text{km}^2$, we gave watersheds a score of 1.

Uncertainties: Effect of road crossings varies among road surface types, road construction methods, and stream crossing types (bridge, culvert, etc.). Influences of these types should be examined at the local scale.

3. Diversions Density

Source: National Hydrography Dataset

Description: Density of canals, which is an indicator of surface flow diversions

Justification: Surface flow diversions decrease flow volume, increase water temperature, and create barriers to dispersal (DRACTU 2016).

Data compilation: We downloaded data from the NHDplus website (<http://www.horizon-systems.com/nhdplus/>). We selected canals from the flowlines shapefile. We calculated the number of canals for each HUC12 watershed. If density of or canals is $\geq 0.1/\text{km}^2$, we gave watersheds a score of 1.

Uncertainties: Criteria used for identifying and classifying diversions differ among states.

4. Wildfire Hazard Potential

Source: U.S. Forest Service Fire Modeling Institute

Description: Percent of catchment classified as high or very high wildfire hazard potential

Justification: High-intensity wildfires have significant impacts on habitat of isolated trout populations (Sedell et al. 2015). Impacts include loss of riparian vegetation, stream warming, increased surface flows, landslides, and sedimentation.

Data compilation: We obtained a raster of wildfire hazard potential from the RMRS Fire Lab (<https://www.firelab.org/project/wildfire-hazard-potential>). We used the Tabulate Area tool to calculate percentage of each HUC12 that that has high or very high fire risk. If percentage of high/very high cover was > 0 the watershed was coded as 1.

Coldwater Fish Sensitivity

1. Threatened and endangered fish

Sources: U.S. Fish and Wildlife Service

Description: Presence of federally threatened or endangered cold water fish species in a stream segment

Justification: We determined that segments of streams containing federally protected species are highly sensitive to changes in land use and climate that result in habitat changes.

Data compilation: We downloaded critical habitat or current range shapefiles for individual threatened or endangered species from the USFWS website (<https://ecos.fws.gov/ecp/report/table/critical-habitat.html>). We used a spatial join to determine if threatened or endangered species with critical habitat were present in each HUC 12 watershed. Watersheds were coded as 1 if ≥ 1 species was present.

2. Riparian vegetation departure

Source: LANDFIRE

Description: Indicator of decrease in riparian cover relative to natural conditions

Justification: Areas with reduced cover of native riparian vegetation have lower bank stability and stream shading, both of which are important components of native trout habitat (Beschta 1997, Winward 2000, DRACTU 2016).

Data compilation: We created this shapefile using methods similar to those developed the Riparian Condition Assessment Tool (Mafarlane et al.). We calculated percent riparian cover for each catchment using the LANDFIRE Existing Vegetation Type layer (<https://www.landfire.gov/>). We also calculated the amount of riparian cover expected under pre-Euro-American influences using the LANDFIRE Biophysical Setting layer, which represents vegetation cover predicted by modeling natural conditions. We calculated a riparian departure index for each HUC12 watershed by dividing existing riparian cover by modeled riparian cover. If departure index was < 0.30, the stream segment was coded as 1.

3. Watershed elevation

Sources: USGS

Description: Mean elevation of HUC12 watershed

Justification: Previous stream assessments have determined that sensitivity to effects of climate change decreases with increasing elevation (DRACTU 2016, Rice et al. 2017).

Data compilation: We downloaded a USGS digital elevation model from the Databasin website (<https://databasin.org/>). We used the spatial analyst tool to calculate percentage of each HUC12 watershed that is greater than 7500 feet (2286 m), following the cut off value identified by DRACTU (2016) in their assessment of Dolores River trout populations. If > 70% of a watershed was < 2286 m, the watershed was coded as 1.

Coldwater Fish Adaptive Capacity

1. Mean August water temperature

Source: U.S. Forest Service NORWEST stream temperature projections

Description: Indicator of potential expansion of coldwater fish habitat as a result of warming

Justification: Some stream section are currently too cold in the summer for successful reproduction of native trout (Roberts et al. 2013). These sections may become essential spawning sites in a warmer climate (Isaak and Hubert 2004, Harig and Fausch 2002).

Data compilation: We obtained data from the NORWEST spatial statistical stream network website (<https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST/ModeledStreamTemperatureScenarioMaps.shtml>). Spatial statistical stream network models were used to apply mean August water temperature to stream reaches. Models contained 12 variables. Two variables (air temp and stream discharge) were calculated at the scale of basin. An additional 10 variables were calculated at the scale of reaches or catchments. Climate projections included A1B emissions scenarios applied to 10 GCMs selected because of low bias across the region. A relationship of changes in air temperature to changes in stream temperature was applied across each basin and an adjustment was made for each segment, reflecting the observation that cooler stream warm more slowly than warm streams. We gave HUC12 watersheds a score of 1 if at least one stream segment within the watershed was projected to have mean August temperatures below the temperature range of ideal trout habitat (9-11 ° C) during the 1993-2011 period.

2. Springs and groundwater-dependent wetlands

Sources: National Hydrography Dataset, National Wetland Inventory

Description: Density of springs and groundwater-dependent wetlands in watersheds

Justification: Springs perform key functions in coldwater fish habitat, including maintenance of flows in perennial streams and stream temperature regulation (Winter 2007, Torgersen et al. 1999). Groundwater-supported wetlands provide numerous services, including the maintenance of volume, quality, and temperature of water discharged into streams (Bedford and Godwin 2003). Palustrine emergent wetlands are most likely to be supported by groundwater in the region's mountainous areas.

Data compilation: We downloaded the NHDplus point shapefiles (<http://www.horizon-systems.com/nhdplus/>) and NWI polygon shapefiles (<https://www.fws.gov/wetlands/>) for each state in the region, merged the data into single shapefiles, and selected springseep and palustrine emergent wetland features for export. We used a spatial join to calculate the number of springs and palustrine emergent wetlands in each HUC12 watershed. If number of springs or wetlands was > 0, watersheds were coded as 1.

Uncertainties: As with most large-scale inventories, the NWI and NHD databases are incomplete and uneven in their coverage. We feel, however, that these sources of data can be useful for a coarse assessment of spring and wetland locations.

3. Subsurface heterogeneity

Source: US Geological Survey

Description: Presence of underlying karst or pseudokarst in a watershed

Justification: The underlying geology of a region influences groundwater recharge, groundwater discharge, and the movement of surface water and groundwater through a watershed (Ford and Williams 2013, Hartmann et al. 2017). In the Southwest, subsurface heterogeneity includes karst systems composed of soluble carbonate bedrock and pseudokarst systems composed of volcanics, sedimentary rocks, and evaporates, all of which are capable of conveying groundwater (Weary and Doctor 2014). The distribution of these systems influences groundwater and surface water dynamics, as well as vulnerability and resistance of aquifers to groundwater withdrawal and climate change (Hartmann et al. 2017). In areas without subsurface heterogeneity, sensitivity of flows to changes in temperature, precipitation, and surface water use is greater.

Data compilation: We downloaded the USGS national karst map (https://water.usgs.gov/ogw/karst/kig2002/jbe_map.html), derived primarily from maps prepared by the individual states. These data were compiled to delineate the distribution of karst, potential karst, and pseudokarst areas of the United States. We used a spatial join to determine if karst or pseudokarst (subsurface heterogeneity) was present in HUC12 watersheds. If subsurface heterogeneity is present, the watershed was coded as 1.

Uncertainties The karst map data are preliminary and were compiled from multiple sources at various spatial resolutions. Because of differences in projection and scale of the various

geologic datasets, spatial errors and location inconsistencies are noticeable along some state boundaries, particularly coastlines and riparian borders.

4. Beaver capacity

Sources: USGS, LANDFIRE

Description: Indicator that a stream segment has capacity for beaver dams

Justification: In semiarid regions, beaver dams enhance adaptive capacity of trout habitat through numerous means including lowering of water temperatures, restoration of natural floodplain dynamics, addition of stream heterogeneity, and creation of barriers to nonnative fish invasion (Stumpff and Cooper 1996, Pollock et al. 2015). Presence of woody vegetation is the primary control on the capacity of a stream to support construction of beaver dams (Macfarlane et al. 2017). Beavers are removed and dams are destroyed, however, where management conflicts occur due to roads and other infrastructure.

Data compilation: We downloaded a USGS digital elevation model from the Databasin website (<https://databasin.org/>). We applied the Extract by Mask tool to extract DEM cells representing stream elevations, using a flowline raster. To obtain slope, we divided the difference between maximum and minimum elevation by the flowline length.

We downloaded the existing vegetation cover layer from the LANDFIRE website (<https://www.landfire.gov/>). We reclassified aspen, woody riparian, and deciduous shrub types as suitable vegetation for food and building material. We also reclassified roads, mines, and developed land as potential management conflicts. We calculated area of suitable vegetation and management conflicts within the 100m riparian buffers for each perennial stream segment. A perennial stream segment was determined to have capacity for beavers if (a) slope was greater than zero and less than 20%; (b) suitable vegetation covered at least 10% of the riparian buffer, and (c) management conflicts covered less than 10% of the buffer. If a HUC12 catchment contained at least 5 km of stream segments with beaver capacity, we coded it with 1.

Uncertainties: We did not include variables such as low flow volume, peak flow volume, and stream confinement which influence whether dams can be built or how long they will persist. These variables should be considered at local scales. Such an analysis for the state of Utah can be found at <http://brat.joewheaton.org/brat-data/utah-brat>.

5. Highly protected land in catchment

Source: U.S. Geological Survey

Description: Area within watershed managed to maintain a natural state

Justification: Streams with high levels of protection, such as those in wilderness areas and national parks, have fewer anthropogenic impacts than those surrounded by multiple-use lands. We assume that successful management for adaptive capacity is most possible where the vast majority of a watershed has been managed to maintain a natural state.

Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (<https://gapanalysis.usgs.gov/padus/data/download/>). We selected features to create a

shapefile of polygons representing areas with GAP status of 1 or 2, which indicate that an area has permanent protection from conversion of natural land cover and a management plan in operation to maintain a natural state. We used the Intersect tool to calculate the area of these lands within HUC12 watersheds. Watersheds were coded as 1 $\geq$ 70% is protected land.

Riparian Corridors Exposure

1. Change in flow volume or timing 2040

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Differences between projections of mean annual cumulative streamflows, mean daily streamflows, and mean center of flow mass timing for historical and future periods, used as an indicator of future change in habitat suitability

Justification: Perennial flows are required by all fish species. Peak flows induce reproductive behavior of many fishes, provide instream habitat for spawning, and facilitate reproduction and survival of riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002). In addition, timing of high flows influences reproductive success of fish, riparian plants, and other organisms associated with streams in the American Southwest (Mahoney and Rood 1998, Nesler et al. 1988).

Data compilation: We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

For stream volume, we calculated the difference between projections for the historical period of 1977-2006 and the future period of 2030-2059. We calculated the difference in projected center of flow timing from projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1. We gave each HUC 12 a score of 1 if at least one of the following occurred at stream segments within the watershed: (a) the difference between historical projections and future projections of mean annual flow is ≥ 1 cfs; (b) the difference between historical projections and future projections of mean summer flow is ≥ 1 cfs; (c) change towards earlier center of flow mass timing ≥ 14 days, a period of length that could influence reproductive success of riparian vegetation.

Uncertainties: Only one emissions scenario (A1B) was used for projections. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

2. Groundwater and surface water use in watershed

Sources: Multiple state agencies, National Hydrography Dataset

Description: Density of wells (number/km²) reported by state water management agencies within catchments; density of canals, which is an indicator of surface flow diversions

Justification: Groundwater withdrawal influences the volume of both groundwater and surface water, impacting riparian ecosystems at southwestern streams (Stromberg et al. 2005). Withdrawal increases in response to declining surface flows, creating stress on riparian communities during periods of drought (Mix et al. 2012, Castle et al. 2014). Surface flow diversions decrease flow volume and create barriers to dispersal (DRACTU 2016).

Data compilation: Arizona wells: data are from the Arizona Groundwater Well Site Inventory (<http://www.azwater.gov/azdwr/gis/>), which is a statewide database that contains well locations, construction, and water level measurements for wells that have been located and sampled in the field originally by the USGS and since 1990 by Arizona Department of Water Resources.

Colorado wells: a dataset of well applications in Colorado is from HydroBase, the Department of Water Resources master database (<http://cdss.state.co.us/GIS/Pages/GISDataHome.aspx>). We selected applications whose current status is “well constructed” to include in the shapefile.

New Mexico wells: the New Mexico Office of the State Engineer Point of Diversions layer includes well locations, surface declarations, or surface permits (<http://gisdata-ose.opendata.arcgis.com/>). These data were extracted from the OSE W.A.T.E.R.S. (Water Administration Technical Engineering Resource System) database and geo-located (mapped).

Utah Wells: we selected points representing wells using the category “UNDERGROUND” from the point of diversion shapefile produced by the Utah Division of Water Rights (<http://www.waterrights.utah.gov/gisinfo/wrcover.asp>). The WRPOD shapefile is a complete record of point of diversion locations taken from the Division's day to day operating database.

We merged data from the four states into a single shapefile. Using a spatial join, we calculated the number of wells in each HUC12 watershed. Given the widespread presence of wells in the regions, we examined the data for a cut off value that indicated substantial groundwater use in a catchment.

We selected canals from the NHDplus flowlines shapefile (<http://www.horizon-systems.com/nhdplus/>). We calculated density of canals for each watershed. If density of wells or canals is $\geq 0.1/\text{km}^2$, we gave watersheds a score of 1.

Uncertainties: Criteria used for identifying and classifying wells and diversions differ among states.

4. Riparian vegetation departure

Source: LANDFIRE

Description: Indicator of decrease in riparian cover relative to natural conditions

Justification: Departure of riparian cover from expected conditions is an indicator of effects of anthropogenic stressors including development, invasive species, and altered disturbance regimes.

Data compilation: We created this shapefile using methods similar to those developed the Riparian Condition Assessment Tool (Macfarlane et al.). We calculated percent riparian cover for each catchment using the LANDFIRE Existing Vegetation Type layer (<https://www.landfire.gov/>). We also calculated the amount of riparian cover expected under pre-Euro-American influences using the LANDFIRE Biophysical Setting layer, which represents

vegetation cover predicted by modeling natural conditions. We calculated a riparian departure index for each HUC12 watershed by dividing existing riparian cover by modeled riparian cover. If departure index was < 0.30 , the stream segment was coded as 1.

5. Major dams in watershed

Sources: U.S. Geological Survey

Description: Presence of major dams within watersheds. Major dams are structures 50 feet or more in height with a normal storage capacity of 5,000 acre-feet or more, and a maximum storage capacity of 25,000 acre-feet or more.

Justification: The widespread construction of dams has had numerous and well-documented effects on streamflows in the Southwest. These effects include decreases in peak flows, increases in baseflows, and changes in timing of short and long-term fluctuations in discharge volume (Graf 1999, Magilligan and Nislow 2005). Additional downstream effects include, decreased sediment loads and stream incision (Novack 2006). These alterations lead to reductions in native riparian vegetation and increases in nonnative species (Cooper et al. 1999, Dewine and Cooper 2007, Mortenson and Weisberg 2010).

Data compilation: We downloaded data from the USGS National Map (https://nationalmap.gov/small_scale/mld/dams00x.html). We used the Intersect tool to calculate number of dams in each HUC12 watershed. If at ≥ 1 major dam was present in a watershed, it was coded with a 1.

Riparian Corridors Sensitivity

1. Threatened and endangered terrestrial riparian species

Source: U.S. Fish and Wildlife Service

Description: Presence of threatened or endangered terrestrial riparian species in a catchment

Justification: Segments of streams supporting federally protected species are highly sensitive to changes in land use and climate that result in habitat changes.

Data compilation: We downloaded critical habitat or current range shapefiles for individual threatened or endangered species from the USFWS website (<https://ecos.fws.gov/ecp/report/table/critical-habitat.html>). We used a spatial join to determine the number of species with critical habitat in the HUC12 watersheds. Watershed were coded as 1 if critical habitat for at least one threatened or endangered species was present.

2. Threatened and endangered fish

Sources: U.S. Fish and Wildlife Service

Description: Presence of threatened or endangered fish species in a catchment's streams

Justification: Streams containing federally protected species are highly sensitive to changes in land use and climate that result in changes to streamflows. Riparian ecosystems influence the quality of aquatic habitat through numerous mechanisms (Minkley and Rinne 1985).

Data compilation: We downloaded critical habitat or current range shapefiles for individual threatened or endangered species from the USFWS website (<https://ecos.fws.gov/ecp/report/table/critical-habitat.html>). We used a spatial join to determine the number of species with critical habitat in the HUC12 watersheds. Watershed were coded as 1 if critical habitat for at least one threatened or endangered species was present.

3. Wildfire hazard potential

Source: U.S. Forest Service Fire Modeling Institute

Description: Percent of catchment classified as high or very high wildfire hazard potential

Justification: Along regulated low elevation streams, native woody plants do not recover from high-intensity wildfires as well as nonnative species such as Russian olive and saltcedar (Busch 1995, Smith and Finch 2017). For many wildlife species, the quality of riparian habitat decreases as a result.

Data compilation: We obtained a raster of wildfire hazard potential from the RMRS Fire Lab (<https://www.firelab.org/project/wildfire-hazard-potential>). We used the Tabulate Area tool to percentage of each HUC12 that that has high or very high fire risk. If percentage of high/very high cover was > 0 the watershed was coded as 1.

Riparian Corridors Adaptive Capacity

1. Subsurface heterogeneity

Source: US Geological Survey

Description: Presence of underlying karst or psuedokarst in a watershed

Justification: The underlying geology of a region influences groundwater recharge, groundwater discharge, and the transmission of surface water and groundwater (Ford and Williams 2013, Hartmann et al. 2017). In the Southwest, subsurface heterogeneity includes karst systems composted of soluble carbonate bedrock and pseudokarst systems composed of volcanics, sedimentary rocks, and evaporates capable of conveying groundwater (Weary and Doctor 2014). The distribution of these systems influences groundwater and surface water dynamics, as well as vulnerability and resistance of aquifers to groundwater withdrawal and climate change (Hartmann et al. 2017). In areas without subsurface heterogeneity, sensitivity of flows to changes in temperature, precipitation, and surface water use is greater.

Data compilation: We downloaded the USGS national karst map (https://water.usgs.gov/ogw/karst/kig2002/jbe_map.html), derived primarily from maps prepared by the individual States. These data were compiled to delineate the distribution of karst and potential karst and pseudokarst areas of the United States. We used a spatial join to

determine if karst or pseudokarst (subsurface heterogeneity) was present in HUC12 watersheds. If subsurface heterogeneity is present, the watershed was coded as 1.

Uncertainties The karst map data are preliminary and were compiled from multiple sources at various spatial resolutions. Because of differences in projection and scale of the various geologic datasets, spatial errors and location inconsistencies are noticeable along some state boundaries, particularly coastlines and riparian borders.

2. Springs in watershed

Sources: National Hydrography Dataset

Description: Density of springs in watersheds

Justification: In arid regions, springs are instrumental in maintaining surface flows in streams, thereby encouraging growth and survival of riparian vegetation (Winter 2007).

Data compilation: We downloaded the NHDplus point shapefiles (<http://www.horizon-systems.com/nhdplus/>) for each basin in the region, merged the data into a single shapefile, and selected the springseep features for export. We used a spatial join to calculate the number of springs in each HUC12 watershed. If at ≥ 1 spring was present, watersheds were coded as 1.

Uncertainties: As with most large-scale inventories, the NHD database is incomplete and uneven in its coverage. We feel, however, that this sources of data can be useful for a coarse assessment of spring locations.

3. Watershed natural cover

Sources: LANDFIRE

Description: Percentage of watersheds with natural cover types, used as a measure of overall condition.

Justification: Development and vegetation conversion can alter rates of interception and infiltration, and evapotranspiration, leading to increased rates of runoff, decreases in groundwater recharge, and changes in timing and volume of surface flows (Wyatt et al. 2015). Adaptive capacity of riparian ecosystems is therefore greater in areas where there are fewer cumulative effects of development, agriculture, and invasive species.

Data compilation: We obtained an existing vegetation type (EVT) raster for the regions from the LANDFIRE website (<https://www.landfire.gov/>). We reclassified the EVT_Phys attribute, with 1 = natural cover types and 0 = Exotic Tree-Shrub, Exotic Herbaceous, Quarries-Strip Mines-Gravel Pits, Developed values, or Agricultural. We used spatial analyst tools to calculate percent natural cover for each HUC12 watershed. We coded watersheds a 1 if natural cover is $\geq 95\%$.

4. Highly protected land in watershed

Source: U.S. Geological Survey

Description: Area within watershed managed to maintain a natural state

Justification: Stream corridors with high levels of protection, such as those in wilderness areas and national parks, have fewer anthropogenic impacts than those surrounded by multiple-use lands. We assume that successful management for adaptive capacity is most likely where the vast majority of a watershed has been managed to maintain a natural state.

Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (<https://gapanalysis.usgs.gov/padus/data/download/>). We selected features to create a shapefile of polygons representing areas with GAP status of 1 or 2, which indicate that an area has permanent protection from conversion of natural land cover and a management plan in operation to maintain a natural state. We used the Intersect tool to calculate the area of these lands within HUC12 watersheds. Watersheds were coded as 1 if at least 70% is protected land.

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