Aquatic-Riparian Climate Change Vulnerability Assessment

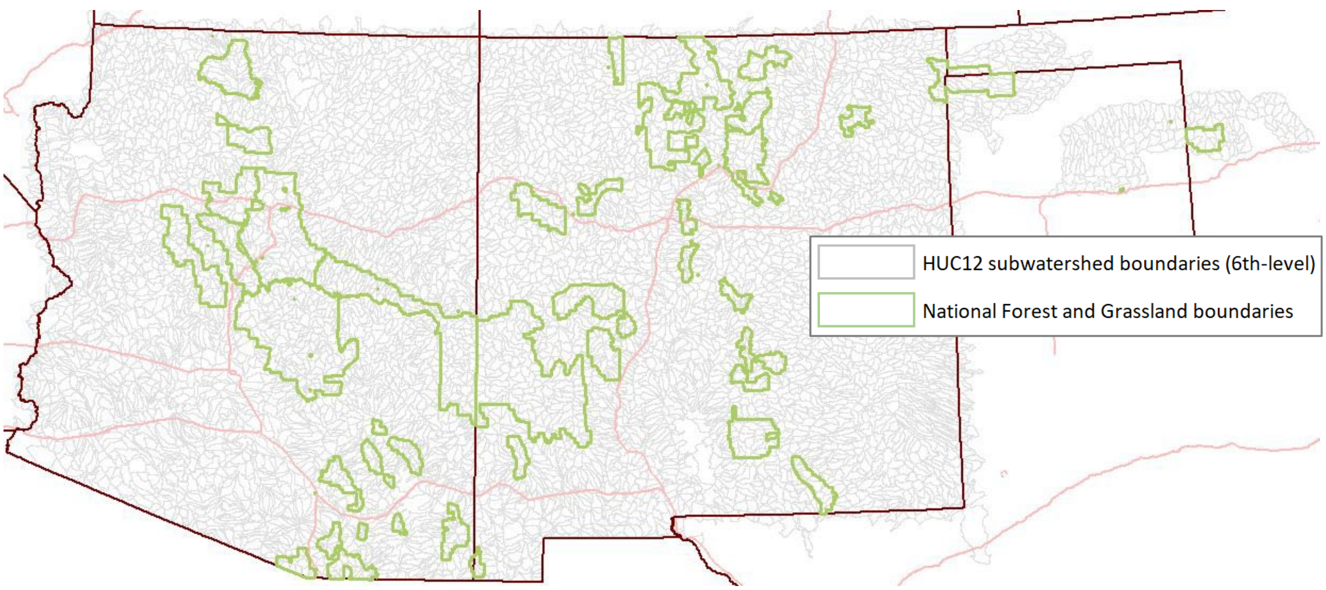
EXECUTIVE REPORT

USDA Forest Service – Southwestern Region – Enterprise Program

Introduction and Background

Land managers are considering ongoing and potential effects of climate and drought on natural resources to coordinate responses for the protection of ecosystems and their water supply, aquatic and riparian biodiversity, and other ecosystem services (Smith and Friggens 2017). Though climate vulnerability of these systems remains understudied (Mott Lacroix et al. 2017), the Rocky Mountain Research Station (RMRS) of the USDA Forest Service, The Nature Conservancy (TNC), and other organizations have developed assessments, tools, and methods for evaluating the vulnerability of specific localities and key ecosystem components. The Aquatic-Riparian Climate Change Vulnerability Assessment (ARCCVA) adds to prior climate assessments (e.g., Friggens et al. 2013) through implementation of a regionwide vulnerability assessment using sufficient thematic detail to support natural resource policy and management prioritization, watershed assessment, monitoring systems, and effects analyses of landscape-scale projects. This work builds on an approach established by Smith and Friggens (2017) and adds additional indicators and spatial extent. The ARCCVA partially fulfills requirements of the Forest Service Climate Scorecard (USDA Forest Service 2020b) as well as the vulnerability assessment requirement of the agency's Climate Adaptation Framework (USDA Forest Service 2020c), both of which are used to support the next step of adaptation strategy. The ARCCVA includes subwatershed-scale reporting (HUC12) for all of Arizona and New Mexico along with the watersheds of Oklahoma and Texas panhandles that intersect Forest Service lands (Figure 1). The assessment is supported by existing data sources on over two dozen intrinsic and climate-related indicators of watershed condition, riparian, and aquatic habitat.

Figure 1: The distribution of subwatersheds included in the ARCCVA for Arizona, New Mexico, Oklahoma, and Texas in relation to National Forests and Grasslands of the Southwestern Region (green boundaries).



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Assessment Overview

As with most climate vulnerability assessments, the ARCCVA is designed to provide information about current and potential threats to important resource values to inform land manager priorities (e.g., USDA Forest Service 2019), effects analyses, and related assessments such the Watershed Condition Classification (USDA Forest Service 2011). The ARCCVA examines vulnerability at the subwatershed level (USGS Hydrologic Unit Code 12) based on the three components of climate vulnerability: exposure, sensitivity, and adaptive capacity (Friggens et al. 2013, Glick et al. 2011):

- Exposure – The climatic or ecological forces affecting the target ecosystems or their elements within an area of interest. Increasing exposure corresponds with increasing vulnerability and negative impacts.
- Sensitivity – The known or predicted susceptibility of target ecosystems or their elements to negative impacts from exposure. Increasing sensitivity corresponds with increasing vulnerability.
- Adaptive Capacity – The potential of target ecosystems or elements to cope with given levels of exposure and sensitivity. Increasing adaptive capacity corresponds with positive impacts and lower vulnerability.

Metrics of exposure include *intrinsic* indicators such as *percent natural cover* and metrics that are directly associated with 21st century climate trends, such as changing stream temperatures and flows. Sensitivity and adaptive capacity metrics are based on the intrinsic characteristics of subwatersheds that infer negative and positive impacts from exposure. We leverage existing data sources to represent 23 individual metrics of exposure, sensitivity, and adaptive capacity (Figure 2) to represent vulnerability of riparian and aquatic resources. Each of the metrics involve characteristics of threat or resilience for each subwatershed, many of which are familiar to similar assessments (e.g., Smith and Friggens 2017). We analyze and scale raw data values to represent metrics and calculate scores for each of the three vulnerability components. The best available data sources were used and may not reflect recent changes in landscape condition, such as recent large wildfires. Additionally, this is a region-wide assessment, that while using best available data, may not capture or properly represent local detail within a subwatershed. Appendix A has descriptions of metrics and data sources, intermediate scoring, and vulnerability ratings. Change detection tools such as LCMS can be utilized to evaluate areas of recent change.

Subwatersheds in this vulnerability assessment are stratified by temperature (coldwater, intermediate, and warmwater[1]) as well as presence or absence of perennial stream segments for three mutually exclusive categories:

- Coldwater – Subwatersheds with perennial stream segments and where August mean stream temperatures are ≤ 17 °C.
- Intermediate – Subwatersheds that meet the coldwater temperature criteria, but where perennial waters are largely absent.
- Warmwater – Subwatersheds that do not meet the coldwater temperature threshold and includes subwatersheds with and without perennial stream segments.

The temperature divisions are a general assignment for this assessment only and are not intended to replace more specific state or local requirements for individual species distributions. Only those subwatersheds that contain perennial stream segments as designated in the USGS National Hydrography Dataset (NHD) are assessed with perennial metrics. Only about 6% of watersheds in the study area (Figure 1) are defined as

[1] *Due to the scale of this analysis, different data sources and objectives, the temperature stratifications and definitions used here do not necessarily coincide with state or other defined temperature classifications and are not intended to replace those more specific or local determinations*.

coldwater systems, likely a decline from characteristic pre-European levels. Another 15% are considered intermediate, those subwatersheds that may meet the coldwater threshold, but are associated with intermittent or ephemeral stream flows. The remaining watersheds are categorized as either warmwater – perennial (20%) or warmwater – non-perennial (59%). The majority of metrics involve perennial features while non-perennial subwatersheds are represented by fewer data inputs. Note that the metric evaluating change in stream temperature suitable for fish species is based upon the subwatershed classification (Figure 2). The temperature thresholds are different for coldwater or warmwater fish species. This analysis will not evaluate coldwater fish species habitat in a warmwater classified system and vice versa, even though on a local scale not represented in this analysis, both temperature regimes can and do occur within a subwatershed. A coldwater classified subwatershed is evaluated specifically for coldwater fish, though warmwater reaches likely occur at lower elevations of the same subwatershed. Conversely, a warmwater classified subwatershed is evaluated for warmwater fish. For reaches of coldwater habitat that occur within a warmwater classified subwatershed and are not represented in this analysis, those reaches will not be properly described at this scale. However, any sections of coldwater habitat in a warmwater classified subwatershed would be at higher risk from temperature changes since the system as a whole is already showing as a warmwater regime.

The authors acknowledge that perennial springs, seeps, and smaller flowing stream segments may be present in some subwatersheds deemed non-perennial. Where they occur, these features can have outsized ecological importance and should be considered accordingly (Chambers et al. 2013). We acknowledge that perennial waters were historically more prevalent (Zipper et al. 2021). However, the information available at the time of this assessment precludes alternative perennial metrics for these subwatersheds.

Figure 2: Summary of exposure, sensitivity, and adaptive capacity metrics (indicators) and their relationships to intermediate scoring and vulnerability rating for coldwater, intermediate, warmwater subwatersheds.

Element	Vulnerability Component	Metric Type	Metric	Intermediate Scoring	ARCCVA Vulnerability Rating
Coldwater - Perennial	Exposure	Intrinsic	Road Crossing Density	Intrinsic Coldwater Exposure	Coldwater - Perennial Vulnerability
			Diversion Density		
			Wildfire Risk		
		Climate Change	Change in Annual Stream Flow	Coldwater Climate Change Exposure	
			Change in Summer Stream Flow		
			Change in Stream Temperature Suitable to Coldwater Fish		
			Upland Climate Change Vulnerability Assessment (CCVA)		
	Sensitivity	Intrinsic	Presence of T&E Riparian Species	Intrinsic Coldwater Sensitivity	
			Presence of T&E Coldwater Fish		
	Adaptive Capacity	Intrinsic	Contemporary Water Temperature	Intrinsic Coldwater Adaptive Capacity	
			Relative Number of Springs and GDE		
			Percent Karst or Pseudokarst		
			Beaver Dam Capacity		
			Percent Protected Lands		
Intermediate - Non-perennial	Exposure	Intrinsic	Road Crossing Density	Intrinsic Intermediate Exposure	Intermediate - Non-perennial Vulnerability
			Diversion Density		
			Wildfire Risk		
		Climate Change	Upland Climate Change Vulnerability Assessment (CCVA)	Intermediate Climate Change Exposure	
	Sensitivity	Intrinsic	Presence of T&E Riparian Species	Intrinsic Intermediate Sensitivity	
			Presence of T&E Coldwater Fish		
	Adaptive Capacity	Intrinsic	Relative Number of Springs and GDE	Intrinsic Intermediate Adaptive Capacity	
			Percent Karst or Pseudokarst		
			Beaver Dam Capacity		
			Percent Protected Lands		
Warmwater - Perennial	Exposure	Intrinsic	Well Density	Intrinsic Warmwater - Perennial Exposure	Warmwater - Perennial Vulnerability
			Dam Density		
			Wildfire Risk		
		Climate Change	Change in Annual Stream Flow	Warmwater - Perennial Climate Change Exposure	
			Change in Summer Stream Flow		
			Change in Stream Flow Timing		
			Change in Stream Temperature Suitable to Warmwater Fish		
			Upland Climate Change Vulnerability Assessment (CCVA)		
	Sensitivity	Intrinsic	Presence of T&E Riparian Species	Intrinsic Warmwater - Perennial Sensitivity	
			Presence of T&E Warmwater Fish		
	Adaptive Capacity	Intrinsic	Relative Number of Springs and GDE	Intrinsic Warmwater - Perennial Adaptive Capacity	
			Percent Karst or Pseudokarst		
			Percent Natural Cover		
			Percent Protected Lands		
Warmwater - Non-perennial	Exposure	Intrinsic	Well Density	Intrinsic Warmwater - Non-perennial Exposure	Warmwater - Non-perennial Vulnerability
			Dam Density		
			Wildfire Risk		
		Climate Change	Upland Climate Change Vulnerability Assessment (CCVA)	Warmwater - Non-perennial Climate Change Exposure	
	Sensitivity	Intrinsic	Presence of T&E Riparian Species	Intrinsic Warmwater - Non-perennial Sensitivity	
			Presence of T&E Warmwater Fish		
	Adaptive Capacity	Intrinsic	Relative Number of Springs and GDE	Intrinsic Warmwater - Non-perennial Adaptive Capacity	
			Percent Karst or Pseudokarst		
			Percent Natural Cover		
			Percent Protected Lands		

The temperature stratifications and definitions used here do not necessarily coincide with state or other defined temperature classifications and are not intended to replace those more specific or local determinations.

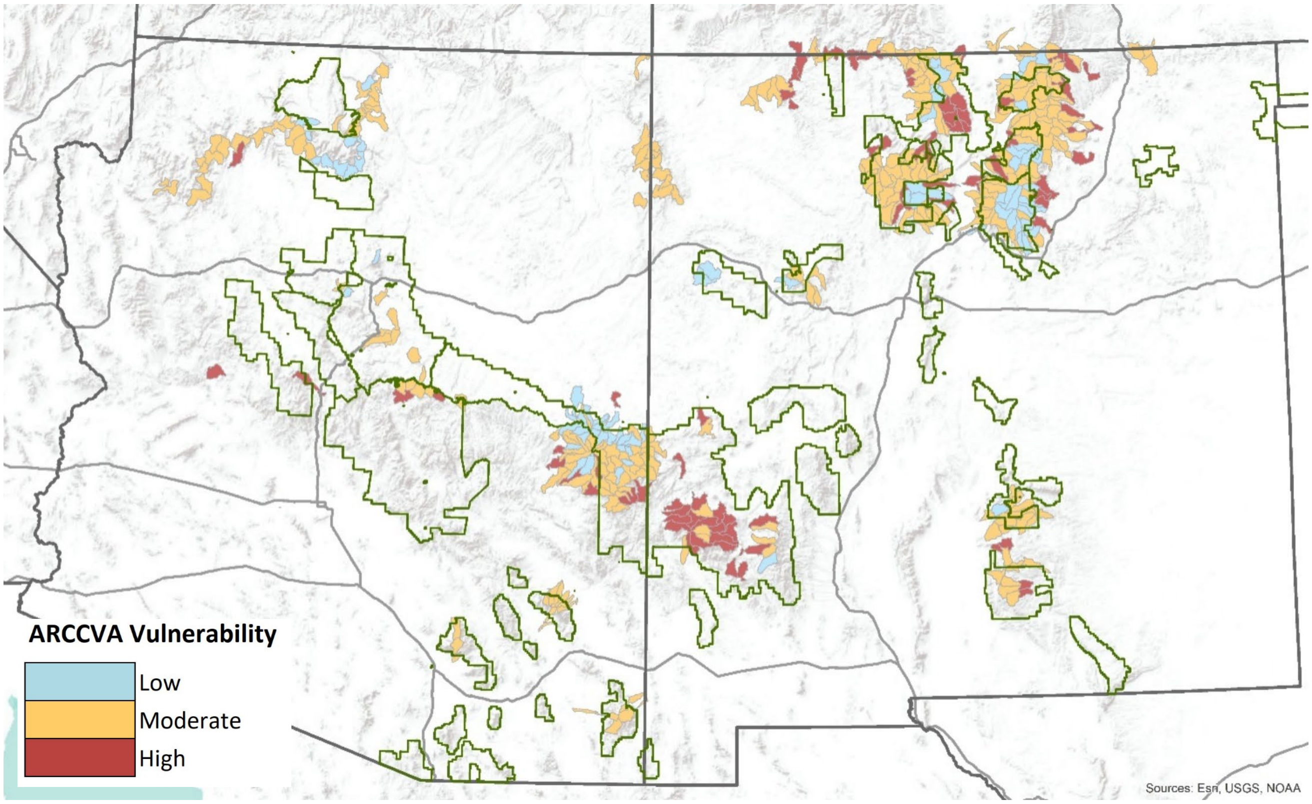
Coldwater Subwatersheds

Coldwater Vulnerability

Coldwater vulnerability ratings are only developed for subwatersheds with perennial segments that have contemporary water temperatures as informed by NorWeST stream temperature data (Isaak 2016) that support coldwater species. Individual species temperature ranges are variable and can be defined in a number of ways, such as maximum survivable temperature levels, daily maximum levels, optimal breeding temperatures ranges, averages, or ideal growth ranges. The threshold for this assessment is perennial stream segments within the watershed being ≤ 17 °C. This threshold is based upon key references (U.S. Fish and Wildlife Service 2021, Zeigler et al. 2013), correspondence to the current distribution of coldwater fish populations, and agency expert input. This definition of coldwater is not intended to replace more specific local determinations or specific species temperature ranges. The coldwater stratification for ARCCVA is carried out using 1993 to 2011 August mean stream temperatures from the NorWeST stream temperature database. As with warmwater ratings, only those subwatersheds with perennial stream segments as designated in the USGS National Hydrography Dataset (NHD) are rated for the perennial metrics. As a result, there are no coldwater ratings for non-perennial subwatersheds regardless of elevation or temperature. Subwatersheds that are deemed non-perennial but meet the temperature designation for coldwater (≤ 17 °C) are broken out into their own category – intermediate, non-perennial. The vulnerability ratings for coldwater systems utilize a full suite of both intrinsic and climate-exposure metrics, with combined scores accounting for exposure, sensitivity, and adaptive capacity. Again, because adaptive capacity represents the ability of the system to absorb and adjust to change, it has a compensatory effect on vulnerability ratings (Figure 3).

For vulnerability calculations, if the combined numeric score of exposure and sensitivity *minus* adaptive capacity is less than 0 then the watershed is rated as low vulnerability (Figure 3). These subwatersheds have higher adaptive capacity and therefore lower vulnerability, all else being equal. If the combined score numeric is greater than 0 but less than 2, then the subwatershed is rated as moderate vulnerability. These subwatersheds have higher combined exposure and sensitivity scores than adaptive capacity and therefore represent elevated vulnerability. Where the combined score is greater than 2 the subwatershed is rated as high vulnerability. For these subwatersheds, exposure and sensitivity together are much higher than total adaptive capacity and represent the highest instances of vulnerability relative to other subwatersheds. This rating system may be conservative given the bias of having more metrics for exposure and sensitivity than for adaptive capacity. The rating thresholds of 20% and 50% that are used to separate departure categories of low, moderate, and high also suggest that the rating system is conservative in comparison to the conventional thresholds of 33% and 66% (Barret et al. 2010, USDA Forest Service 2014, 2020a).

Figure 3: Assessment results for coldwater vulnerability.



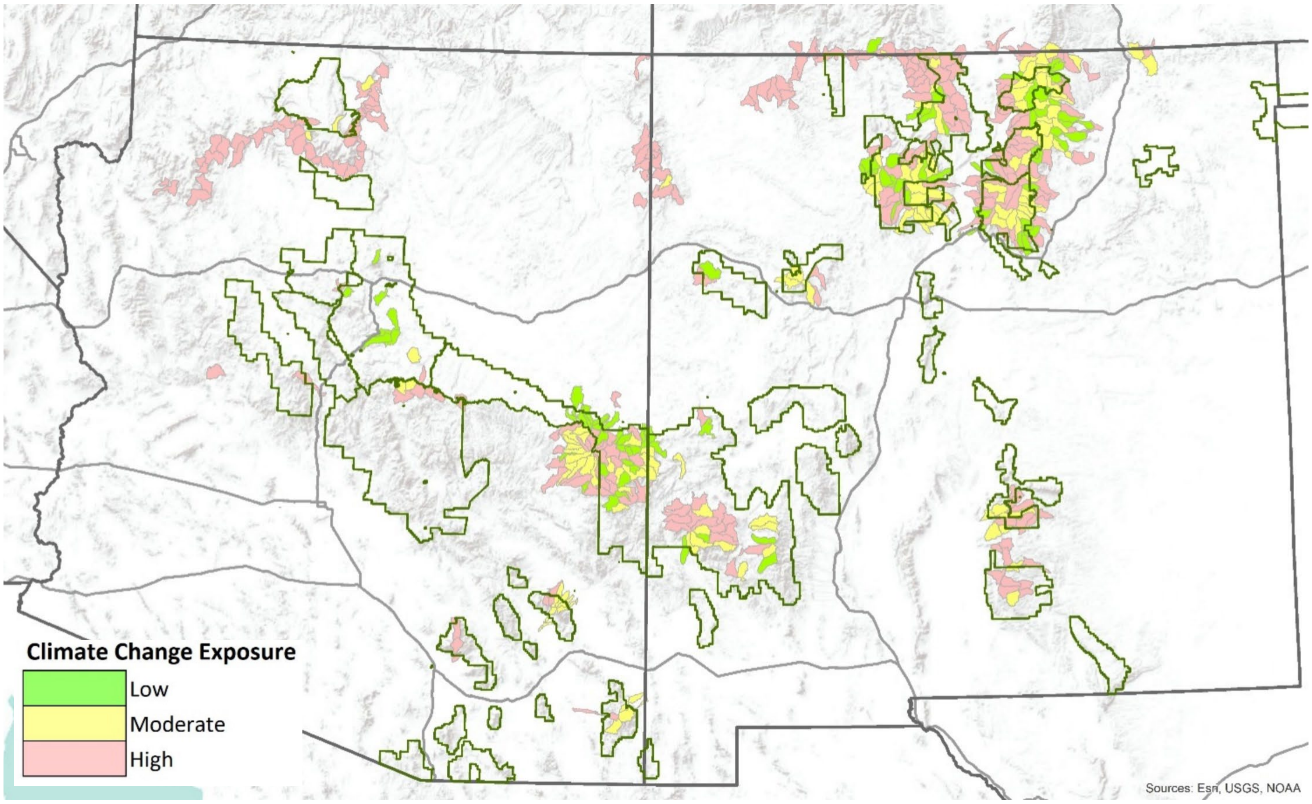
Coldwater Climate Change Exposure

Multifactor scoring is used to determine coldwater climate change exposure ratings based on metrics of flow volume and temperature along with upland CCVA scores. Similar to the warmwater counterpart, the climate exposure ratings (Table 1) for coldwater subwatersheds are specific to those with perennial waters (Figure 4). Metrics used to determine warmwater climate change exposure (Figure 4) include annual and summary stream flow volumes, and stream temperatures, where ratings are computed by determining the percent change in each metric over time and then rescaling results from 0 to 1 (Appendix A). The ratings are also influenced by upland CCVA results, where upland CCVA represents the forecast departure from characteristic climate conditions for each watershed (Triepke et al. 2019).

Table 1: Rating system for climate change exposure for both warmwater and coldwater perennial subwatersheds (see Appendix B).

Rating	Description
Low	Subwatersheds with low individual scores for all flow and temperature metrics (annual flow change, summer flow change, flow timing change, stream temperature change) and with an upland CCVA rating of low or moderate.
Moderate	Subwatersheds with neither low (see above) or high (see below) climate change exposure ratings.
High	Subwatersheds with high individual scores in one or more of the flow and temperature metrics. Subwatersheds are also rated as high if the upland CCVA rating is high in combination with one or more stream flow or temperature metrics scored as moderate departure.

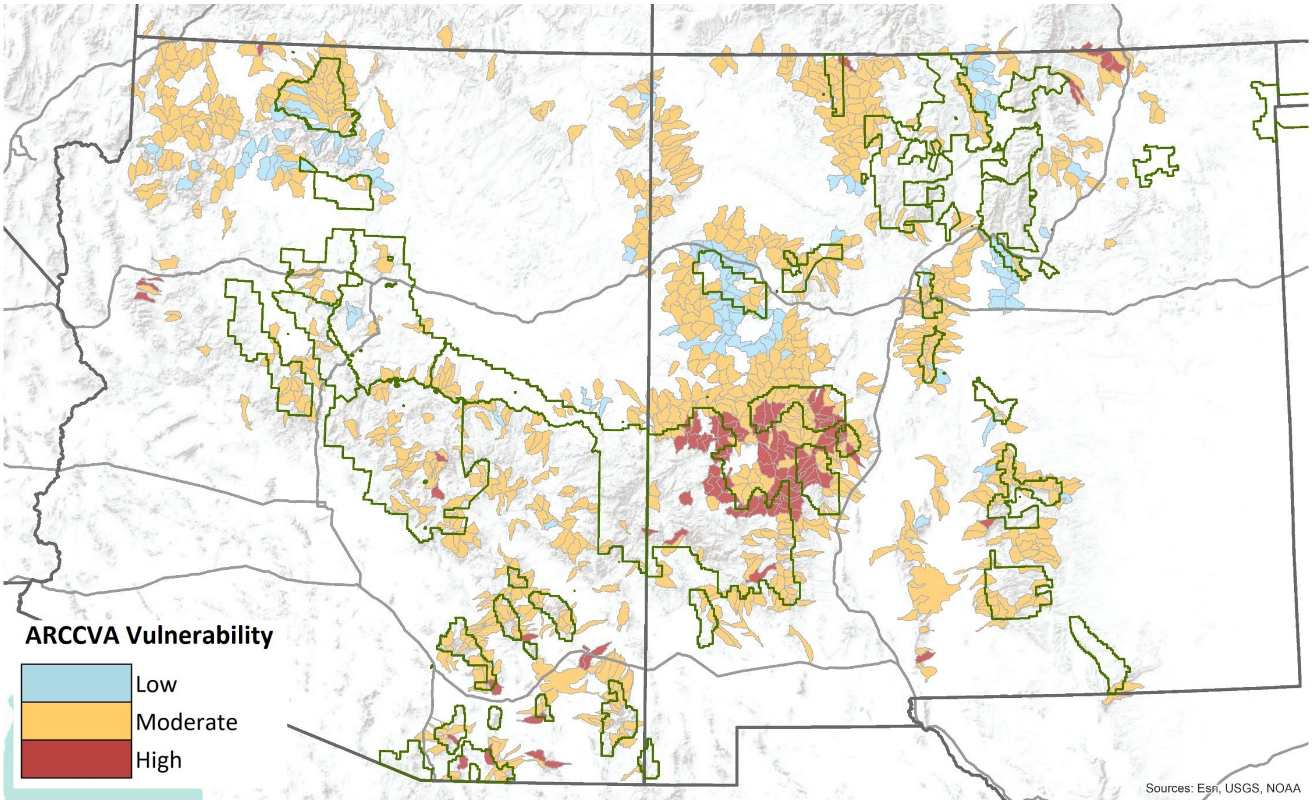
Figure 4: Assessment results for coldwater climate change exposure.



Intermediate Subwatersheds

Subwatersheds that meet the coldwater temperature criteria, but where perennial waters are largely absent are not true coldwater systems, often occurring adjacent to coldwater subwatersheds on high plateaus or mountainous areas. This group of subwatersheds is rated using the same framework as the coldwater subwatersheds, however because they are non-perennial and thus do not have streamflow data, climate change exposure is calculated solely from the upland CCVA (Figure 5).

Figure 5: Assessment results for intermediate vulnerability.



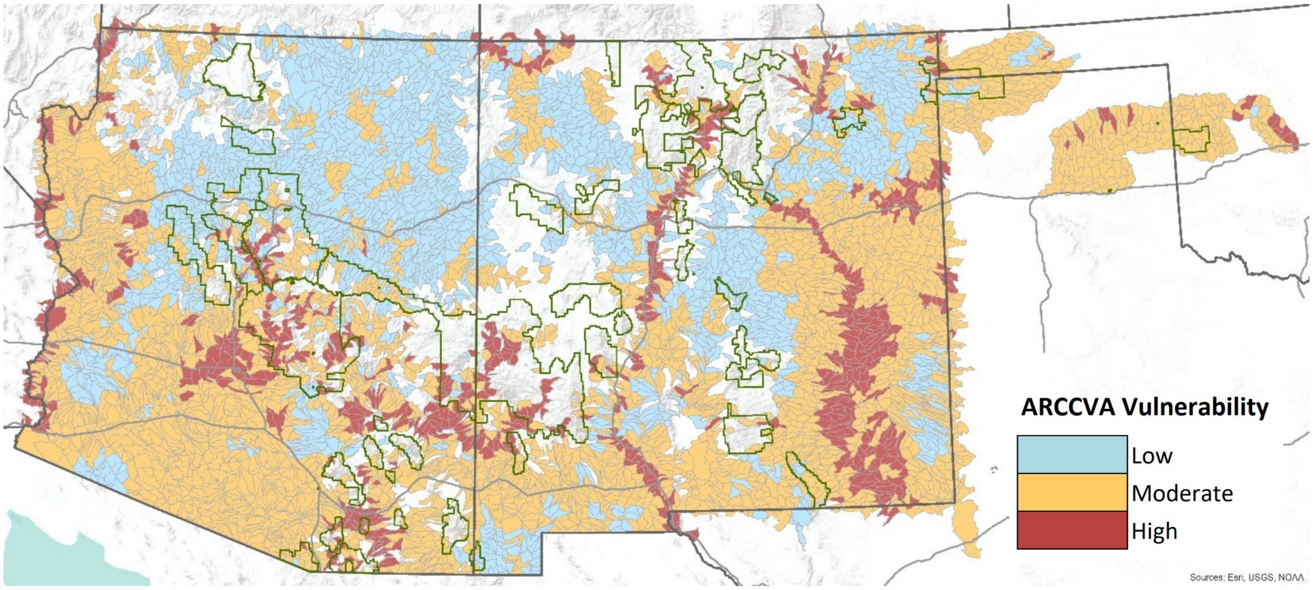
Warmwater Subwatersheds

Warmwater Subwatershed Vulnerability

We developed vulnerability ratings for warmwater subwatersheds based on 14 intrinsic and climate exposure metrics (Figure 2 and Appendix A). We calculate vulnerability as the combined influence of exposure and sensitivity with adaptive capacity. Because adaptive capacity represents the ability of the system to absorb and adjust to change and stress, it has a compensatory effect on vulnerability ratings to positively offset the potential negative impacts of exposure and sensitivity.

Following the same protocol as for the coldwater systems, a given subwatershed is rated as low if the combined intermediate scores are less than 0 (sensitivity *plus* exposure *minus* adaptive capacity). These areas have higher adaptive capacity than the negative impacts associated with exposure and sensitivity and are therefore considered to have low vulnerability. If the combined numeric score is greater than 0 and less than 2 then the watershed vulnerability is rated as moderate. Where the combined score is greater than 2 the watershed is rated as high.

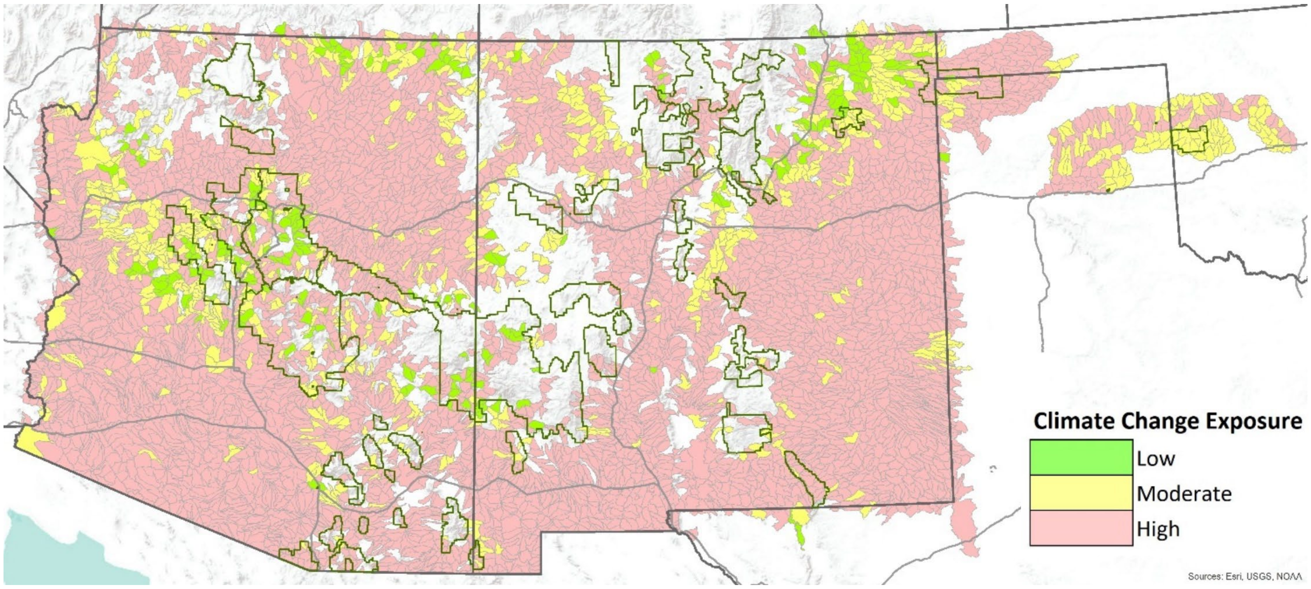
Figure 6: Assessment results for warmwater subwatershed vulnerability.



Warmwater Climate Change Exposure (Subwatersheds with perennial stream segments)

Multifactor scoring is used to determine the climate exposure ratings for 21st century climate trends on warmwater resources in subwatersheds with perennial streams using the rating system in Table 1. Five metrics are used to determine warmwater climate change exposure (Figure 2) including annual and summary stream flow volumes, flow timing, and stream temperatures, where ratings are computed by determining the percent change in each metric over time and then rescaling results from 0 to 1 (Appendix A). The ratings are also influenced by upland CCVA results, where upland CCVA represents the forecast departure from characteristic climate conditions for each watershed (Triepke et al. 2019).

Figure 7: Assessment results for warmwater climate change exposure.



Overall Ratings – All Subwatersheds

The climate change exposure rating (Figure 8, Table 2) is a comprehensive assessment of climate-specific metrics for all subwatersheds of the ARCCVA. The role of this assessment is to focus on vulnerability associated with 21st-Century climate trends, and to provide some indication of climate change exposure to non-perennial subwatersheds. This assessment brings together the previously described climate exposure ratings developed for warmwater, intermediate, and coldwater subwatersheds that have perennial stream segments. For non-perennial subwatersheds, CCVA ratings alone are used to assign climate change exposure. While the upland CCVA excluded desert ratings for upland vegetation due to the exceptional drought resistance of these systems, the ratings are nevertheless useful for ARCCVA because they accurately represent the water stress in aquatic and riparian areas that desert ecosystems are experiencing. Since the upland CCVA did not include the portions of the National Grasslands in Oklahoma and Texas, the climate exposure ratings from the similar NatureServe Climate Change Vulnerability (Comer et al. 2019) are utilized for these areas.

Figure 8: Climate change exposure ratings for all subwatersheds assessed with ARCCVA.

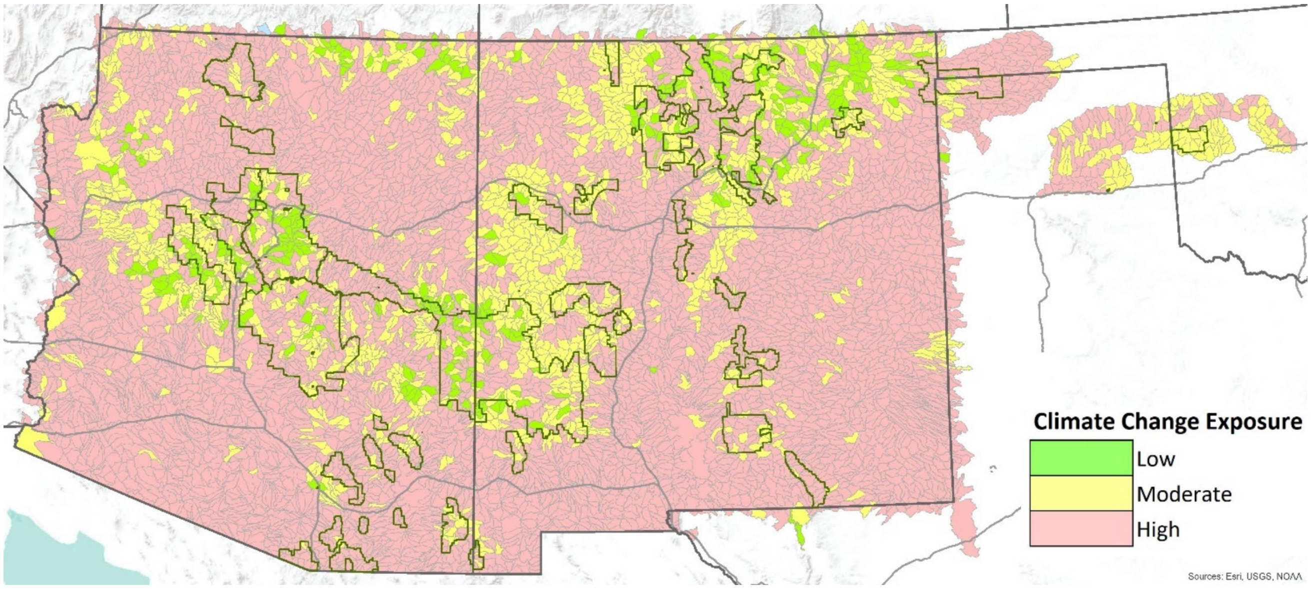


Table 2. The number and percentage of subwatersheds for vulnerability specific to climate change (exposure only).

Climate Change Vulnerability (exposure)	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater (perennial)	Warmwater (non-perennial)	Total
Low	79	33	188	30	330
Moderate	112	464	344	482	1,402
High	218	539	832	3,383	4,972
Not Analyzed	0	0	1	1	2
Total	**409 (6%)**	**1,036 (15%)**	**1,365 (20%)**	**3,896 (59%)**	**6,706**
Low	19%	3%	14%	1%	5%
Moderate	27%	45%	25%	12%	21%
High	53%	52%	61%	87%	74%
Not Analyzed	0%	0%	< 1%	< 1%	< 1%

The overall vulnerability rating combines the three components of climate vulnerability, exposure, sensitivity, and adaptive capacity, of each subwatershed for a single rating that focuses on the cumulative influence of the components. The ARCCVA suggests that the majority (59%, Table 3) of subwatersheds are moderately vulnerable to ongoing threats and climate trends (overall vulnerability) and that vulnerability is disproportionately higher in coldwater and intermediate subwatersheds. Not surprisingly, vulnerability averages much higher when looking only at future trends in climate (exposure) with over 70% (Table 2) of subwatersheds as high vulnerability and where exposure is disproportionately higher in warmwater watersheds.

Figure 9: Vulnerability ratings for all subwatersheds assessed with ARCCVA.

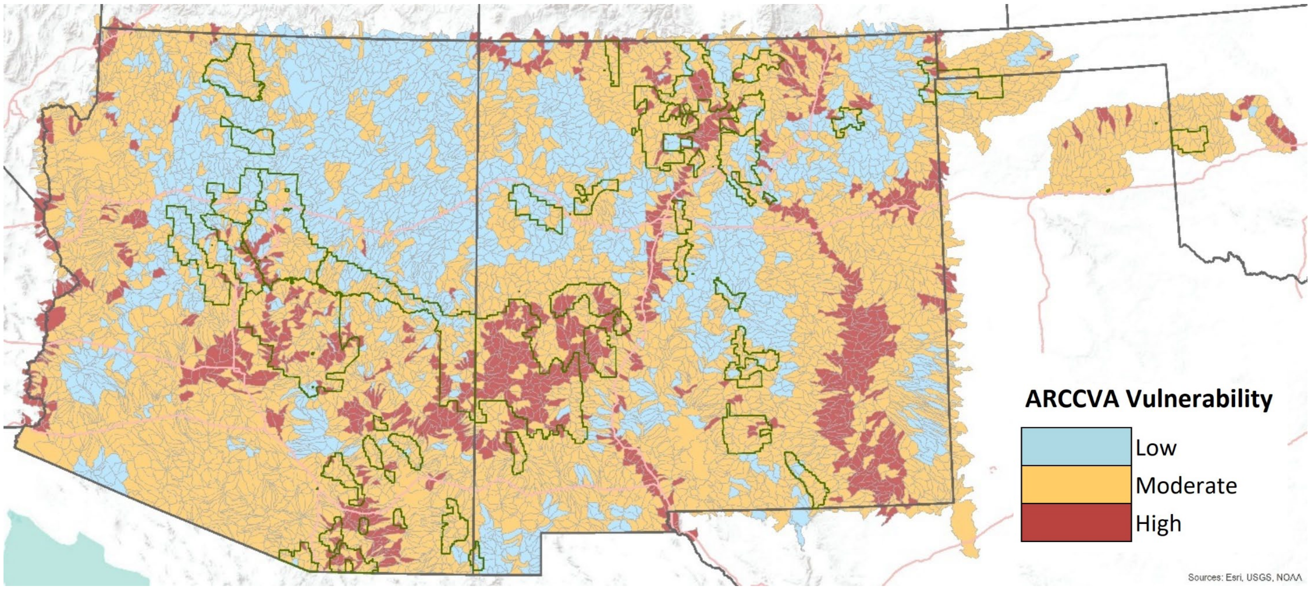


Table 3. The number and percentage of subwatersheds for ARCCVA vulnerability rating.

Vulnerability Rating	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater (perennial)	Warmwater (non-perennial)	Total
Low	75	107	236	1,511	1,929
Moderate	257	840	633	2,248	3,978
High	77	89	496	137	799
Total	**409 (6%)**	**1,036 (15%)**	**1,365 (20%)**	**3,896 (59%)**	**6,706**
Low	18%	10%	17%	39%	29%
Moderate	63%	81%	46%	58%	59%
High	19%	9%	36%	4%	12%

Outputs

The ARCCVA is an all-lands subwatershed-based vulnerability assessment built on nearly two dozen metrics of exposure, sensitivity, and adaptive capacity to represent the vulnerability of aquatic and riparian resources. This work helps to fulfill the Forest Service requirement for vulnerability assessment and to set the stage for the Regional Climate Adaptation Strategy. Vulnerability assessments are important for informing the adaptation strategy and related watershed assessments and for the prioritization of restoration work.

The ARCCVA is stratified according to temperature and perennial stream status. The perennial stratification elevates the ecological value of subwatersheds with perennial flows and to highlight uncertainty for non-perennial subwatersheds where fewer metrics are available to drive vulnerability. Vulnerability and climate change exposure ratings are considered conservative by methods in the ARCCVA used to assign ratings to each subwatershed (see appendices A and B).

Factors of uncertainty in the ARCCVA results reflect 1) our assumptions about the relative importance of perennial waters, federally listed fish, aquatic, and riparian plant species; 2) the availability and accuracy of important input data and how inputs are combined in scoring and rating algorithms; 3) variability and accuracy among climate forecasts for the Southwest and corresponding inferences upon flow metrics and the upland CCVA; and 4) the relative influence of exposure, sensitivity, and adaptive capacity inputs to ARCCVA results. As contemporary observations and independent analyses are used to validate the upland CCVA, there is a need to use similar resources to test relationships between ARCCVA vulnerability predictions and real-world ecological processes and species trends to assess and refine ARCCVA outputs.

Outputs and products for ARCCVA include this summary report, a geodatabase available at the R3 GIS Library (https://www.fs.usda.gov/detailfull/r3/landmanagement/gis), and an interactive Storymap for viewing and customized reporting (https://storymaps.arcgis.com/stories/2d998ed0bc8743c9b6f36edc18e88ee8). The StoryMap allows the end user to consider each ARCCVA metrics individually. Table 4 is a quick guide to the metrics and associated scores and ARCCVA ratings in the geodatabase. The geodatabase reflects the core of ARCCVA and can be used in spatial analysis and landscape prioritization by leveraging individual or collective vulnerability components.

Table 4: Quick guide to attribute fields of the ARCCVA and web tool, and relationships among vulnerability ratings and individual metrics of exposure, sensitivity, and adaptive capacity.

Geodatabase Attribute Field	Attribute Name	Attribute Type
HUC_12	6th-field hydrologic unit code (HUC12)	NHD identifier/code
HU_12_NAME	6th-field hydrologic unit name	NHD identifier/code
RoadCrossingDensity	**Road Crossing Density** score (0 to 1)	Metric, intrinsic EXPOSURE
DiversionDensity	**Diversion Density** score (0 to 1)	Metric, intrinsic EXPOSURE
WildfireRisk	**Wildfire Risk** score (0 to 1)	Metric, intrinsic EXPOSURE
WellDensityScaled	**Well Density score** (0 to 1)	Metric, intrinsic EXPOSURE
DamsScaled	**Dam Density score** (0 to 1)	Metric, intrinsic EXPOSURE
FlowTimingChange (Perennial only)	**Change in Stream Flow Timing** score (0 to 1)	Metric, climate change EXPOSURE
WarmFishTempPct (Perennial only)	**Change in Stream Temperature Suitable to Warmwater Fish Habitat** (0 to 1)	Metric, climate change EXPOSURE
AnnFlowChange (Perennial only)	**Change in Annual Stream Flow** score (0 to 1)	Metric, climate change EXPOSURE
SummFlowChange (Perennial only)	**Change in Summer Stream Flow** score (0 to 1)	Metric, climate change EXPOSURE
ColdTempFishPct (Perennial only)	**Change in Stream Temperature Suitable to Coldwater Fish Habitat** score (0 to 1)	Metric, climate change EXPOSURE
UplandCCVANum	**Upland Climate Change Vulnerability Assessment (CCVA)** score (0 to 1)	Metric, climate change EXPOSURE + SENSITIVITY
TEColdwaterFish	**Presence of Coldwater T&E Fish** (0, 1)	Metric, intrinsic SENSITIVITY
TE_Riparian	**Presence of Riparian or Aquatic T&E Species** (0, 1)	Metric, intrinsic SENSITIVITY
TE_WarmFish	**Presence of Warmwater T&E Fish** (0, 1)	Metric, intrinsic SENSITIVITY
BeaverDamCapacity	**Beaver Dam Capacity** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
ContWaterTemp (Perennial only)	**Contemporary Water Temperature** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
SpringGDEscaled	**Relative Number of Springs and GDEs** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
PctKarst	**Percent Karst or Pseudokarst** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
HProLandinCatchPct	**Percent Protected Lands** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
WatershedNaturalCover	**Percent Natural Cover of Vegetation** (0 to -1)	Metric, intrinsic ADAPTIVE CAPACITY
ClimateChangeExposure	**Climate Change Exposure** intermediate rating	Intermediate rating, climate EXPOSURE
VulnCategory	**Vulnerability** rating	Vulnerability rating VULNERABILITY

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Appendix A – ARCCVA Geodatabase Attribute Fields

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Default attribute data code, running value	Attribute table record ID	OBJECTID	running number
6th-field hydrologic unit code (HUC12). Source data are NHD.	NHD identifier/code	HUC_12	HUC identifier number (text format)
6th-field hydrologic unit name. Source data are NHD.	NHD identifier/code	HU_12_NAME	HUC alpha identifier
Either 'Yes' or 'No', indicating whether the HUC12 unit is considered in calculations for three metrics (ColdTempFishPct, WarmFishTempPct, ContWaterTemp) based on NorWeSt. NorWeST stream temperature data and climate scenarios are hosted by the Rocky Mountain Research Station NorWeST web site for the western US. https://www.fs.usda.gov/rm/boise/AWAE/projects/NorWeST.html	Text	NorWestTemps	Yes, No
Either 'Perennial Streams Present' or <Null> indicating whether NHD stream/river segments in the HUC12 unit are classified as perennial. Source data are NHD.	Filter	PerennialStream	Perennial Streams Present, <Null>
Numeric version of HUC12 code for joining table data based on subwatershed codes. Source data are NHD.	Attribute table join ID	HUC12Join	HUC identifier number (number format)
Upland Climate Change Vulnerability Assessment (CCVA) rating for the HUC12 unit, either Low, Moderate, High, and Very High. Values also include <Null> and 'No CCVA'. Source data are from Triepke et al. (2019) for subwatersheds in AZ and NM. For the subwatersheds in OK and TX where the National Grasslands occur the NatureServe Habitat Climate Change Vulnerability Index (Comer et al. 2019) was used and rescaled to match the upland CCVA scoring.	Metric, climate change - EXPOSURE + SENSITIVITY (IMPACT)	UplandCCVA	Low, Moderate, High, Very High, No CCVA
Either 1, 2, 3, 4, 5, or <Null> indicating the number of T&E warmwater fish species with critical habitat or range overlapping the HUC12 unit. Critical Habitat-based species include: *Catostomus discobolus yarrowi*, *Cyprinella formosa*, *Cyprinodon macularius*, *Gila cypha*, *Gila ditaenia*, *Gila elegans*, *Gila intermedia*, *Gila purpurea*, *Gila seminuda* (=*robusta*), *Hybognathus amarus*, *Ictalurus pricei*, *Lepidomeda vittata*, *Meda fulgida*, *Notropis girardi*, *Notropis simus pecosensis*, *Plagopterus argentissimus*, *Ptychocheilus lucius*, *Tiaroga cobitis*, & *Xyrauchen texanus*; Range-based species include *Cyprinodon elegans*, *Empetrichthys latos*, *Gambusia nobilis*, *Gila nigrescens*, *Notropis buccula*, & *Poeciliopsis occidentalis*. Source data are from FWS web pages for individual species (e.g., https://ecos.fws.gov/ecp/species/3536).	Filter	WarmFishCountTE	1, 2, 3, 4, 5, <Null>
Values of 1-8 and <Null> representing the count of riparian T&E wildlife and plant species with range overlapping the HUC12 unit. Species include: *Ambystoma tigrinum stebbinsi*, *Calidris canutus rufa*, *Charadrius melodus*, *Cirsium wrightii*, *Gammarus hyalleloides*, *Grus americana*, *Kinosternon sonoriense longifemorale*, *Oxyloma haydeni kanabensis*, *Popenaias popeii*, *Pyrgulopsis neomexicana*, *Pyrgulopsis texana*, *Rallus longirostris yumanensis*, *Spiranthes delitescens*, *Sterna antillarum*, *Sterna antillarum browni*, *Thermosphaeroma thermophilus*, *Tryonia alamosae*, & *Tryonia cheatumi*. Source data are from FWS web pages for individual species (e.g., https://ecos.fws.gov/ecp/species/3536).	Filter	RipCountTESpecies	1, 2, 3, 4, 5, 6, 7, 8, <Null>

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Change in Summer Stream Flow score for each HUC12 unit is based on Western US Stream Flow Metrics data and determined by first computing miles of stream and then calculating the percent of the watershed stream miles to exceed rating thresholds (calculated with perennial segments only; Appendix B), before rescaling values on a 0-1 scale. Some <Null> values present. Western U.S. Stream Flow Metrics is an online dataset of modeled flow metrics for streams in major river basins of the Western US for historical and future climate change scenarios. Source data represent a 2030-2059 climate forecast and are from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, climate change - EXPOSURE	SummFlowChange	0 to 1, <Null>
Change in Annual Stream Flow score for each HUC12 unit with change in flow volume based on Western US Stream Flow Metrics data and determined by first computing miles of stream and then calculating the percent of the watershed stream miles to exceed rating thresholds (calculated with perennial segments only; Appendix B), before rescaling values on a 0-1 scale. Some <Null> values present. Western U.S. Stream Flow Metrics is an online dataset of modeled flow metrics for streams in major river basins of the Western US for historical and future climate change scenarios. Source data represent a 2030-2059 climate forecast and are from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, climate change - EXPOSURE	AnnFlowChange	0 to 1, <Null>
Change in Stream Temperature Suitable to Coldwater Fish Habitat score for each coldwater classified HUC12 unit is determined by first computing meters of suitable perennial stream using 1993-2011 temperatures and then calculating the percent of the watershed stream meters to exceed rating thresholds in 2030-2059 (calculated with perennial segments only; Appendix B), before rescaling values on a 0-1 scale. Note that the metric is applied for the entire HUC12 unit when classified as coldwater even though a mix of coldwater and warmwater can occur within the same HUC12. Stream temperature data are for 1993-2011 and the 2030-2059 climate forecast taken from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, climate change - EXPOSURE	ColdTempFishPct	0 to 1, <Null>
Change in Stream Temperature Suitable to Warmwater Fish Habitat score for each warmwater classified HUC12 unit determined by first computing miles of stream and then calculating the percent of the watershed stream miles to exceed rating thresholds (calculated with perennial segments only; Appendix B), before rescaling the results as 0-1. Note that the metric is applied for the entire HUC12 unit when classified as coldwater even though a mix of coldwater and warmwater can occur within the same HUC12. Source data represent a 2030-2059 climate forecast and are from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, climate change - EXPOSURE	WarmFishTempPct	0 to 1, <Null>
Upland Climate Change Vulnerability Assessment (CCVA) score for overall upland vulnerability in the HUC12 unit. Watersheds assigned scores of 0 (low), 0.33 (moderate), 0.66 (high), 1 (very high), or <Null> (no assignment). Source data are from Triepke et al. (2019) for subwatersheds in AZ and NM. For the subwatersheds in OK and TX where the National Grasslands occur the NatureServe Habitat Climate Change Vulnerability Index (Comer et al. 2019) was used and rescaled to match the upland CCVA scoring.	Metric, climate change - EXPOSURE + SENSITIVITY	UpCCVANum	0 to 1, <Null>

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Change in Stream Flow Timing score for each HUC12 unit with values rescaled 0-1 indicating the amount the center of flow mass timing has changed. This metric is based on Western US Stream Flow Metrics data where stream segments with the center of mass flow timing changed by greater than or equal to 14 days are identified as having a significant flow change. The 14 day threshold is based upon the assessment by Smith and Friggens 2017 in which they felt a change in stream flow timing of 14 days or more could influence both fish and riparian vegetation reproduction. Total miles of perennial stream segments exceeding this significant flow change threshold are calculated for each watershed (Appendix B). Values are calculated as a percentage of total perennial stream segments within a watershed before rescaling values on a 0-1 scale. Some <Null> values present. Western US Stream Flow Metrics is an online dataset of modeled flow metrics for streams in major river basins of the Western US for historical and future climate change scenarios. Source data represent a 2030-2059 climate forecast and are from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, climate change - EXPOSURE	FlowTimingChange	0 to 1, <Null>
Road Crossing Density score on perennial stream segments for each HUC12 unit. Density values represent the number of road crossings per square kilometer in the watershed, rescaled from 0 to 1, where 1 represents the maximum density. Source data are from USGS TIGER roads database (https://www.census.gov/programs-surveys/geography/guidance/tiger-data-products-guide.html) and NHD stream flow lines.	Metric, intrinsic - EXPOSURE	RoadCrossingDensity	0 to 1, <Null>
Diversion Density score indicating the relative density of diversions (canals) in each HUC12 unit. Density values are calculated based on the total number of canals per square kilometer in a watershed and then rescaled as a range of 0-1. Source data are NHD at individual basin scale, count per square kilometer.	Metric, intrinsic - EXPOSURE	DiversionDensity	0 to 1, <Null>
Wildfire Risk score based on percentage of each HUC12 unit with either high or very high wildfire hazard potential and then rescaled to a range of 0-1. Source data are 2018 wildfire hazard ratings, https://www.firelab.org/project/wildfire-hazard-potential	Metric, intrinsic - EXPOSURE	WildfireRisk	0 to 1, <Null>
T&E Coldwater Fish Presence in the HUC12 unit. Species included *Oncorhynchus apache* & *Oncorhynchus gilae*. Note: this metric is not rescaled since doing so would dilute the "value" of watersheds with just 1 species despite their importance. However, this makes this attribute inherently weighted heavier than other metrics. Values are either '1' or '<Null>'. Source data are from Forest Service aquatic biologists.	Filter	TEColdwaterFish	<Null> (no), 1 (yes)
Contemporary Water Temperature score indicating perennial water segments in each HUC12 unit where current temperatures are ≤17 degrees C. These segments represent areas that may still provide potential future refugia for coldwater spawning habitat under warmer temperatures. Values are summarized to include percent perennial streams ≤ 17 degrees C and then rescaled from 0 to -1. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact. Source data are from https://www.fs.usda.gov/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml	Metric, intrinsic - ADAPTIVE CAPACITY	ContWaterTemp	0 to -1, <Null>

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Count of Springs mapped in each HUC12 unit, rescaled as a score from 0 to -1. Source data are NHD.	Metric, intrinsic - ADAPTIVE CAPACITY	Springs	-1 to 0, <Null>
Count of Groundwater Dependent Ecosystems (GDE) mapped in each HUC12 unit. Source data are NWI.	Metric, intrinsic - ADAPTIVE CAPACITY	GDEcount	1 to 1564, <Null>
Combined Count of Springs and GDE for each HUC12 unit.	Metric, intrinsic - ADAPTIVE CAPACITY	SpringAndGDEcount	2 to 1580, <Null>
Relative Number of Springs and GDEs in each HUC12 unit. Calculations included tallying total spring counts based on NHD point layers, and then rescaling values on a negative 0-1 scale where -1 represents the maximum count of GDEs found in any of the watersheds. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact.	Metric, intrinsic - ADAPTIVE CAPACITY	SpringGDEscaled	-1 to 0, <Null>
Percent Karst or Pseudokarst in each HUC12 unit with results rescaled from 0 to -1 where -1 represents the maximum percent karst. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact. Source data from 'Karst in the United States: A digital map compilation and database' (Weary and Doctor, Open-File Report 2014–1156) using sandstone, evaporites, piping, volcanics, and carbonites.	Metric, intrinsic - ADAPTIVE CAPACITY	PctKarst	-1 to 0, <Null>
Beaver Dam Capacity metric based on the amount of stream segments within a HUC12 unit that are suitable for beaver dams according to segment slope, mapped riparian vegetation potential, and management conflicts. Values are rescaled from 0 to -1, where -1 represents the watershed with the most length of beaver dam suitable stream segments. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact. Derived data source based perennial segments (NHD) buffered, calculated slope for riparian ERUs. For herb-dominated hydrology the metric is based on EDW subbasins, LANDFIRE vegetation data (EVT, ReMap) and potential management conflict (EVT_PHYS) including Developed-High Intensity, Developed-Low Intensity, Developed-Medium Intensity, Developed-Roads, and Quarries-Strip Mines-Gravel Pits-Well and Wind Pads	Metric, intrinsic - ADAPTIVE CAPACITY	BeaverDamCapacity	-1 to 0, <Null>
Percent Protected Lands of each HUC12 unit with highly protected status, USGS GAP values of 1 or 2. Actual value represents percent of the watershed not of protected lands. The resulting values are rescaled from 0 to -1. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact. Source data are from USGS PADUS (https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/introduction-pad-us-viewer?qt-science_center_objects=0#qt-science_center_objects).	Metric, intrinsic - ADAPTIVE CAPACITY	HProLandinCatchPct	-1 to 0, <Null>
Well Density of reported wells within each HUC12 unit (count per square km). Source data for Oklahoma from https://home-owrb.opendata.arcgis.com/datasets/permitted-groundwater-wells, for Texas from http://www.twdb.texas.gov/mapping/gisdata.asp, for New Mexico from OSE POD data, and for Arizona from groundwater site inventory (ARIZONA DEPARTMENT OF WATER RESOURCES GROUNDWATER SITE INVENTORY (GWSI) DATABASE HANDBOOK HYDROLOGY DIVISION 2019)	Metric, intrinsic - EXPOSURE	WellDensity_1	0 to 9, <Null>

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Well Density within each HUC12 unit rescaled to a range of 0-1 to represent the relative well density.	Metric, intrinsic - EXPOSURE	WellDensityScaled	0 to 1, <Null>
Dam Density for each HUC12 unit representing the relative density of major dams, rescaled from 0 to 1 where 1 representing the watershed with the highest number of major dams present. Source data are Nationwide USGS https://nationalmap.gov/small_scale/mld/dams00x.html (shapefile of major dams in the United States).	Metric, intrinsic - EXPOSURE	DamsScaled	0 to 1, <Null>
Presence of Riparian or Aquatic T&E Species based on the intersection of critical habitat or range with each HUC12 unit, where a value of 1 indicates one or more species and <Null> indicating none. Source data are from FWS web pages for individual species (e.g., https://ecos.fws.gov/ecp/species/3536).	Metric, intrinsic - SENSITIVITY	TE_Riparian	<Null> (no), 1 (yes)
Presence of Warmwater T&E Fish based on the intersection of critical habitat or range with each HUC12 unit, where a value of 1 indicates one or more species and 0 indicating none. Source data are from FWS web pages for individual species (e.g., https://ecos.fws.gov/ecp/species/3536).	Metric, intrinsic - SENSITIVITY	TE_WarmFish	<Null> (no), 1 (yes)
Percent Natural Cover of vegetation within each HUC12 unit, where values are rescaled from -1 to 0, where -1 represents the highest natural cover. As with all adaptive capacity scoring, a negative scale is used as an opposing factor to impact. Natural cover data are from LANDFIRE EVT.	Metric, intrinsic - ADAPTIVE CAPACITY	WatershedNaturalCover	-1 to 0, <Null>
Intrinsic Exposure intermediate score based on the addition of the values for the relevant metrics for the class. For coldwater and intermediate classes, the metrics are 1) Road Crossing Density, 2) Diversion Density, and 3) Wildfire Risk. For warmwater classes, the metrics are 1) Well Density Scaled, 2) Dam Density Scaled, and 3) Wildfire Risk. <Null> values are ignored in intermediate and overall scoring and act as zeros.	Intermediate Score - Intrinsic EXPOSURE	IntExposure	0 to 1.60
Climate Change Exposure intermediate score for future climate exposure based on a composite of the relevant metrics for the class. For coldwater, the metrics are 1) Change in Annual Stream Flow, 2) Change in Summer Stream Flow, 3) Change in Stream Temperature Suitable for Coldwater Fish, and 4) Upland Climate Change Vulnerability Assessment (CCVA) numerical ratings. For warmwater perennial classes, the metrics are 1) Change in Annual Stream Flow, 2) Change in Summer Stream Flow, 3) Change in Stream Flow Timing, 4) Change in Stream Temperature Suitable to Warmwater Fish, and 5) the Upland Climate Change Vulnerability Assessment rating (CCVA). <Null> values are ignored in intermediate and overall scoring and act as zeros.	Intermediate Score - Climate EXPOSURE	ClimateChangeExposure	0 to 4.0

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Intrinsic Sensitivity intermediate score based on a composite of the relevant metrics for the class. For coldwater and intermediate classes, the metrics are 1) Presence of T&E Riparian and Aquatic Species and 2) Presences of T&E Coldwater Fish. For warmwater classes, the metrics are 1) Presence of T&E Riparian and Aquatic Species and 2) Presences of T&E Warmwater Fish. <Null> values are ignored in intermediate and overall scoring and act as zeros.	Intermediate Score - Intrinsic SENSITIVITY	IntSensitivity	0, 1, 2
Intrinsic Adaptive Capacity intermediate score based on a composite of based on a composite of the relevant metrics for the class. For coldwater and intermediate classes, the metrics are 1) Contemporary Water Temperature, 2) Relative Number of Springs and GDEs, 3) Percent Karst or Pseudokarst, 4) Beaver Dam Capacity, and 5) Percent Protected Lands. For warmwater classes, the metrics are 1) Relative Number of Springs and GDEs, 2) Percent Karst or Pseudokarst, 3) Percent Natural Cover, and 4) Percent Protected Lands. <Null> values are ignored in intermediate and overall scoring and act as zeros.	Intermediate Score - Intrinsic ADAPTIVE CAPACITY	IntAdaptCapacity	-3.78 to 0
Impact intermediate score based on the addition of three intermediate exposure and sensitivity scores including 1) Climate Change Exposure, 2) Intrinsic Exposure, and 3) Intrinsic Sensitivity. <Null> values are ignored in intermediate and overall scoring and act as zeros.	Intermediate Score - Impact EXPOSURE + SENSITIVITY	ImpactScore	0 to 5.82
Vulnerability Score based on the addition of 1) Intrinsic Adaptive Capacity intermediate score and the 2) Impact overall score.	Vulnerability Score - (exposure + sensitivity + adaptive capacity) VULNERABILITY	CombinedScore	-3.00 to 4.76
Vulnerability Category Rating of low, moderate, or high based on the combination of 1) Intrinsic Adaptive Capacity intermediate score and the 2) Impact overall score.	Vulnerability Rating - (exposure + sensitivity + adaptive capacity) VULNERABILITY	VulnCategory	Low, Moderate, High
Climate Change Vulnerability intermediate rating based on climate change exposure metrics. Perennial watersheds – Rated low if all of the flow and temperature metrics are rated low and the upland CCVA rating is low or moderate. Watersheds are rated high if one or more of the flow or temperature metrics are rated as high or if flow and temperature metrics are intermediate, but upland CCVA rating is high. All other watersheds are rated as moderate. For non-perennial subwatersheds the upland CCVA ratings are used as a proxy for overall climate change exposure in the absence of the full suite of climate indicators. Since the upland CCVA did not include the National Grasslands, some subwatersheds receive no rating ('Not Analyzed') for the climate change vulnerability.	Summary Climate Rating - All Climate Exposure, 21st-Century climate trends EXPOSURE	ClimateChange Vulnerability	Low, Moderate, High, Not Analyzed

Attribute Description, and Data Source	Attribute Type	Attribute Name	Values
Class – Temperature and perennial/non-perennial stratification: Coldwater, intermediate, or warmwater class combined with perennial status	Filter	Class	Coldwater – Perennial, Intermediate - Non-perennial, Warmwater – Perennial, Warmwater - Non-perennial

Appendix B – Categorical Rating Key for Climate Change Vulnerability

Warmwater (perennial subwatersheds only)

IF:			Result
SummFlowChange	≤ 0.20	*and*	
AnnFlowChange	≤ 0.20	*and*	
WarmFishTempPct	≤ 0.20	*and*	
FlowTimingChange	≤ 0.20	*and*	
IF:			
Upland CCVA	>= 0.66 (High)		***<u>Climate Exposure Moderate</u>***
Upland CCVA	< 0.66 (Low and Moderate)		***<u>Climate Exposure Low</u>***
Otherwise			
IF:			
SummFlowChange	≥ 0.5	*or*	
AnnFlowChange	≥ 0.5	*or*	
WarmFishTempPct	≥ 0.5	*or*	
FlowTimingChange	≥ 0.5	*or*	
Then			***<u>Climate Exposure High</u>***
Otherwise			
IF:			
SummFlowChange	> 0.2 and < 0.5	*or*	
AnnFlowChange	> 0.2 and < 0.5	*or*	
WarmFishTempPct	> 0.2 and < 0.5	*or*	
FlowTimingChange	> 0.2 and < 0.5	*or*	
IF:			
Upland CCVA	>=0.66 (High)		***<u>Climate Exposure High</u>***
Upland CCVA	<0.66 (Low and Moderate)		***<u>Climate Exposure Moderate</u>***

Coldwater (perennial subwatersheds only)

IF:			Result
SummFlowChange	≤ 0.20	*and*	
AnnFlowChange	≤ 0.20	*and*	
ColdTempFishPct	≤ 0.20	*and*	
IF:			
Upland CCVA	>= 0.66 (High)		***Climate Exposure Moderate***
Upland CCVA	< 0.66 (Low and Moderate)		***Climate Exposure Low***
Otherwise			
IF:			
SummFlowChange	≥ 0.5	*or*	
AnnFlowChange	≥ 0.5	*or*	
ColdTempFishPct	≥ 0.5	*or*	
Then			***Climate Exposure High***
Otherwise			
IF:			
SummFlowChange	> 0.2 and < 0.5	*or*	
AnnFlowChange	> 0.2 and < 0.5	*or*	
ColdTempFishPct	> 0.2 and < 0.5	*or*	
IF:			
Upland CCVA	>= 0.66 (High)		***Climate Exposure High***
Upland CCVA	< 0.66 (Low and Moderate)		***Climate Exposure Moderate***