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Executive Summary

Rivers are crucial to supporting biodiversity and providing ecosystem services such as clean drinking water and recreation opportunities, offering far more value to people, wildlife, and ecosystems than might be expected given their small global footprint. Yet rivers are under increasing threat as the climate warms and our populations grow, placing greater stress and demand on freshwater resources. Despite their life-giving importance, few rivers and streams are currently protected from human impacts to their integrity and flow. We have the opportunity now to protect more of these waterways in the United States through a variety of mechanisms.

We offer a rigorous assessment of wild rivers that are currently unprotected and, using various criteria for evaluating their ecological value, quantify and highlight those that are most ecologically important to protect. We focused in particular on identifying rivers and streams throughout the state of Washington with the highest potential for Outstanding National Resource Water (ONRW) or state Wild and Scenic River (W&S) designation, although we anticipate the data provided to be valuable for supporting river protection through other mechanisms, such as the federal Wild and Scenic Rivers Act. Here, we connect designation criteria to statewide data to identify rivers with the greatest potential to achieve formal protection via ONRW or W&S designation. We summarize our key findings and map these rivers statewide to help visualize the "best of the best" river segments and other ecologically important places to seek new protections.

Our assessment shows that, of the 43,261 miles considered, rivers and streams with the highest ONRW potential are generally found in the Olympic Peninsula of northwest Washington and the Cascade Range, though high-scoring rivers and streams were also prevalent in the far northeast and southeast corners of the state (Salmo-Priest and Wenaha-Tucannon wildernesses). Statewide, 2,826 river miles demonstrate outstanding overall ecological value in that they score in the top 25% of all rivers statewide for each of our ONRW objectives (water quality, ecological significance, and cold-water refuge potential). These rivers are remarkable in their achievement of diverse values that do not otherwise tend to strongly coincide spatially. Of these, 603 river miles demonstrated particular ecological value, scoring in the top 25% for all ecological significance indicators (at-risk aquatic species diversity, rarity-weighted species richness, and ecosystem type rarity). Washington's rivers support high numbers of aquatic species identified by the state as Species of Greatest Conservation Need (SGCN); 3,764 river miles are within the ranges of at least 15 aquatic SGCN, while 23,376 river miles are within the ranges of at least 10 of these at-risk species. Many high-scoring, high-elevation rivers and streams also offer crucial thermal refuges for cold-water species. Rivers and streams with the highest W&S potential are widely distributed across the less densely developed portions of the state, offering additional protection opportunities and value. A total of 3,397 river miles scored in the top 25% statewide for all indicators of State Scenic River potential; these rivers achieved high water quality as well as a low degree of modification and high inaccessibility by surface transport. Furthermore, 15 of the top 20 watersheds for ONRW designation and 18 of the top 20 watersheds for W&S designation contain drinking water sources; protection of these waters would help to maintain provision of this vital ecosystem service for generations to come.

In short, tens of thousands of river miles across Washington possess a wide range of ecological values and ecosystem services worthy of protection, whether through state-level designations, federal Wild & Scenic designation, or other available mechanisms. This assessment and the data accompanying it offer scientifically grounded support for identification of the values associated with rivers, streams, and

watersheds across the state of Washington that can inform and support efforts to ensure those values persist.

Introduction

Rivers are the lifeblood of our wild lands. Although rivers, lakes, and other freshwater habitats represent less than 1% of the Earth's surface, they support approximately 10% of all known animal species (Balian et al. 2007) and one-third of all known vertebrates (Dudgeon et al. 2006). They are also estimated to provide one-fifth of the value of all of Earth's ecosystem services (Costanza et al. 1997). Rivers are hot spots of biodiversity and endemism that enable native plants and animals to thrive (Strayer and Dudgeon 2010); they provide clean drinking water for more than half the United States population (Dieter et al. 2018); they offer a wealth of recreation opportunities; and they offer myriad other ecosystem services supporting ecological and human health and well-being (Brauman et al. 2007).

As our planet warms and climate patterns change (Masson-Delmotte et al. 2018), we will see increasing human demands on freshwater systems as well as variability in water supplies (Strayer and Dudgeon 2010, Jackson et al. 2001) such that protecting our freshwater resources will become even more important and more difficult. This is critical for biodiversity, too: Freshwater ecosystems host tremendous biodiversity, including one-third of all vertebrate species, yet freshwater species population declines continue to outpace those of terrestrial and marine systems (Reid et al. 2019; Tickner et al. 2020). Emerging and accelerating threats include changing climatic conditions, biological invasions, infectious diseases, microplastic pollution, and expanding hydropower. Globally, just over one-third of rivers longer than 1,000 kilometers (620 miles) remain free-flowing over their entire length (Grill et al. 2019). Currently, less than 0.5% of river miles in the United States are protected under the Wild and Scenic Rivers Act, which was passed by Congress in 1968 to "preserve certain rivers with outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations" (Public Law 90-542; 16 U.S.C. 1271 et seq.; National Wild and Scenic Rivers System 2020). With mounting public support and growing political will, especially at the federal level, we have the opportunity now to protect more of these important waterways through both state and federal mechanisms.

The goal of this study was to provide a rigorous assessment of wild rivers that are currently unprotected and, using various criteria for evaluating their ecological value, quantify and highlight those that are most ecologically important to protect. Specifically, we sought to identify the factors most important for identifying rivers of high ecological value and with the greatest potential to achieve formal protection. We also sought to map those rivers and streams to help visualize the "best of the best" river segments and the most important ecological places to seek new protections.

We focused in particular on identifying rivers and streams throughout Washington with the highest potential for Outstanding National Resource Water (ONRW) or state Wild and Scenic River (W&S) designation, especially due to their ecological value. (In Washington, these designations are termed Outstanding Resource Waters and State Scenic Rivers.) Under the Clean Water Act, states can apply the ONRW designation to waterways and thereby mandate that water quality be protected and maintained and that any degradation during a particular activity be temporary, minimized, and reversed (in some states, no degradation at all is permitted). In Washington, no rivers are yet designated ONRW; approximately 220 miles are designated W&S. While other means of achieving river protection exist (e.g., the federal Wild and Scenic Rivers Act), which may also benefit from our data, we begin with an emphasis on these regulatory tools because criteria for these designations are clearly defined in a number of states and, when defined, are fairly consistent among states. We matched the best available statewide data to established or likely designation criteria to evaluate each stream segment's designation potential and to identify watersheds with particularly high mileage of high-potential streams. We then illustrate the distribution of these high-value streams and watersheds across the state, highlight the ecological values driving their potential, and assess their potential contribution to drinking water sources. We describe a variety of intended applications of our results, as well as their limitations. Finally, we provide the results of our assessment, along with underlying data layers, as an interactive map hosted by Data Basin for further exploration and visualization.

Methods

Overview

Many spatial prioritization approaches have been developed to identify the best targets for conservation action. Some highly sophisticated systematic approaches (e.g., Moilanen and Kujala 2006, Watts et al. 2009, Tallis et al. 2011) are designed to simultaneously identify suites of priority areas that together maximize all prioritization criteria while minimizing costs or risks (based on, e.g., monetary cost of protection, total area or river miles protected). Some of these methods have even been adapted to directional stream networks such that up- and downstream costs and benefits can be factored into solutions (Moilanen et al. 2008, Hermoso et al. 2012). However, many of these approaches are data-hungry, require considerable technical skill to implement, and produce solutions that are difficult to trace back to the objectives that defined them; in other words, they can behave as "black boxes," the inner workings of which are not always transparent to outside observers.

Our objective was to identify rivers and streams with high ecological value and potential for ONRW or W&S designation using an easy-to-understand, easy-to-communicate, and easy-to-adjust approach. It was not necessary to identify an optimized suite of conservation targets that achieve complementarity in their representation of the various designation criteria or that are subject to constraints defined by risks or costs. Therefore, we chose a simpler prioritization approach that has been used in similar applications with similar objectives (e.g., Hoenke et al. 2014, Martin 2019).

We applied an objective hierarchy framework, which serves to organize nested objectives (after Hoenke et al. 2014; see Fig. 1 for illustrative example). We developed one hierarchical framework for scoring ONRW potential and a second, separate framework for scoring W&S potential (i.e., two distinct analyses). These frameworks allowed us to combine various quantitative datasets to score each river or stream in a transparent, structured, and goal-oriented way. The primary objective defining each hierarchy (e.g., top tier of Fig. 1) was to identify the rivers and streams with the highest potential for ONRW or W&S designation, respectively. Each of these objectives was defined by multiple designation criteria, which formed the second tier of each hierarchy (as in Fig. 1). Finally, the degree to which each river or stream achieves each criterion is assessed based on one or more indicators, which are defined by the available data. These criteria, indicators, and the weights assigned to each to achieve priority scores are described in detail below.

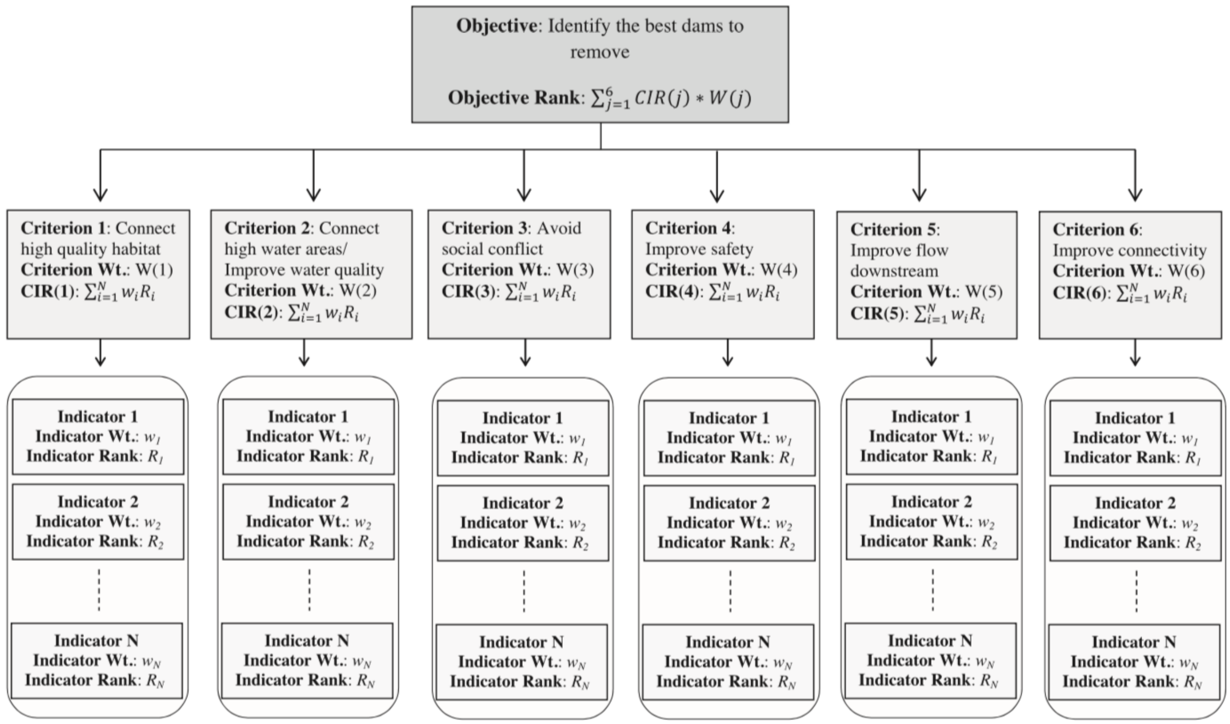

Figure 1. Example of an objective hierarchy framework, in which weighted indicators are used to assess the extent to which criteria defining an overall objective are met. In this example, the framework is used to identify the best dams for removal to achieve ecological and social benefits (Hoenke et al. 2014).

Our analysis was based on hydrography data derived from the publicly available National Hydrography Dataset (NHD; medium resolution, 1:100,000; USGS 2016), with integrated geospatial data (e.g., flow estimates) from NHDPlus Version 2 (1:100,000; EPA 2016). Harrison-Atlas et al. (2017) subsetted this dataset to focus on perennial rivers and streams with continuous flow throughout the year. To do so, they selected River/Stream features, perennial streams, and digitized centerlines for large rivers. These features were further subsetted to include only those with mean annual flow > 1 cubic foot per second (cfs). Finally, they excluded stream segments intended exclusively for mapping purposes to focus only on those representing meaningful water bodies (see Harrison-Atlas et al. 2017 for further details). This subsetted flowlines dataset—43,261 miles total—served as the basis for all analyses summarized in this report. Although intermittent and ephemeral rivers and streams are thereby excluded from consideration, their ecological value cannot be overstated, and they are highly worthy of protection as well (Datry et al. 2018; Shanafield et al. 2020).

Outstanding Resource Waters

To score ONRW potential, we first identified existing criteria or guidelines established by the state of Washington for ONRW designation (Box 1). We matched each criterion to the best available spatial data with statewide coverage (Table 1); these datasets are described in further detail in Appendix A. In some cases, multiple datasets pertaining to different components of a criterion were considered together; we hereafter refer to each of these components as indicators. We then integrated each indicator, then each criterion, into a single overall ONRW potential score.

Box 1. Washington Outstanding Resource Waters designation criteria.

Washington state's antidegradation rules set forth three tiers of protections for surface waters. Tier III applies to designation of outstanding resource waters (WAC 173-201A-330).

Where a high-quality water is designated as an outstanding resource water, the water quality and uses of those waters must be maintained and protected. As part of the public process, a qualifying water body may be designated as Tier III(A) which prohibits any and all future degradation, or Tier III(B) which allows for de minimis (below measurable amounts) degradation from well-controlled activities.

To be eligible for designation, one or more of the following must apply:

*(a) The water is in a relatively pristine condition (largely **absent human sources of degradation**) or possesses **exceptional water quality**, and also **occurs in** federal and state parks, monuments, preserves, wildlife refuges, wilderness areas, marine sanctuaries, estuarine research reserves, or wild and scenic rivers;*

*(b) The water has **unique aquatic habitat types** (for example, peat bogs) that by conventional water quality parameters (such as dissolved oxygen, temperature, or sediment) are not considered high quality, but that are **unique and regionally rare examples** of their kind;*

*(c) The water has both high water quality and regionally unique **recreational value**;*

*(d) The water is of **exceptional statewide ecological significance**; or*

*(e) The water has **cold water thermal refuges** critical to the long-term protection of aquatic species. For this type of outstanding resource water, the nondegradation protection would apply only to temperature and dissolved oxygen.*

Table 1. Indicators used to assess ONRW potential for all rivers and streams in Washington. See Appendix A for details on the source data and/or derivation of these datasets.

Designation Criterion	Indicator	Data Source
Absent human sources of degradation, exceptional water quality	Assessed stream's water quality categorization (see Table 2)	Washington Department of Ecology 2014
	Protected status of adjacent lands (GAP status; see Table 2)	Protected Areas Database of the U.S. (PAD-US v1.4; USGS GAP 2018)

	Total flow and valley bottom modification	Harrison-Atlas et al. 2017 (derived from NHD [USGS 2016], NID [USACE 2016], and Theobald et al. 2016)
Recreational value	Sufficient mean annual flow to support wading and/or boating	Harrison-Atlas et al. 2017 (derived from NHD [USGS 2016])
Ecological significance, unique aquatic habitat types	At-risk aquatic species richness	Derived from WDAFS 2012, USFWS 2019
	Rarity-weighted richness of critically imperiled and imperiled species	NatureServe 2013
	Ecosystem type rarity	Derived from USGS GAP 2011
Cold water thermal refuge	Projected mean August stream temperature (2050)	NorWeST stream temperature model (Isaak et al. 2017)

To quantify "*absen[ce of] human sources of degradation and exceptional water quality*," we first obtained water quality data from the Washington Department of Ecology (2014, Table 1). This public dataset assigns an ordinal water quality category to each assessed river or stream that represents the degree to which the stream supports beneficial uses (e.g., aquatic life, drinking water, recreation), based on multiple measured stream properties. Because not all streams across the state have been assessed, and to more fully assess "*absence of human sources of degradation*," we also considered a derived metric representing the total degree of modification of a stream, which integrates both the degree of flow modification from upstream barriers and the degree of modification of the surrounding valley bottom (or flood plain; Harrison-Atlas et al. 2017). Additionally, we considered the protected status of the lands through which the stream passes (using PAD-US v1.4; USGS GAP 2018), to capture the final component of this criterion ("*occurs in*" lands designated primarily for the purpose of biodiversity conservation).

Rivers and streams may support a wide variety of recreational opportunities, including fishing, swimming, floating, kayaking, whitewater rafting, and motorized boating. It is therefore difficult to identify particular attributes most likely to confer "recreational significance," as these attributes differ among activities. Furthermore, consistent spatial data representing potentially meaningful attributes (e.g., presence of whitewater, boat ramp access, sportfish distributions) are generally unavailable at the state level. Even with such data in hand, recreational significance may still be difficult to estimate due to the complex interaction of these attributes with site accessibility from population centers and historical drivers of recreational use patterns. Consistent statewide data on actual recreational activity patterns and use frequency are also unavailable at meaningful spatial resolutions. We therefore rely on a very coarse indicator of recreation potential for this assessment based on flow. A previous analysis (Harrison-Atlas et al. 2017) categorized rivers and streams into three classes of mean annual flow: flow sufficient to support boating, flow sufficient to support wading, and flow insufficient to support either of these activities (e.g., headwater streams). Here, we very simply consider streams and rivers with sufficient flow to support boating or wading (i.e., with a flow of at least 6 cfs) as having recreation potential, while those with lower flow are not considered to have recreation potential. Though coarse, we expect this indicator to effectively filter out most streams that do not provide recreation opportunities. We encourage *post hoc* assessments of recreational value and activity in high-priority rivers and watersheds using local data where available.

“Ecological significance” is a broad concept that may encompass many attributes of natural systems (e.g., diversity [Noss 1990, Davis et al. 2008], rarity [Chaplin et al. 2000], integrity or intactness [Angermeier and Karr 1994, Parrish et al. 2003], resilience [Ackerly et al. 2010, Beier and Brost 2010]). For this statewide assessment, we considered three indicators that together represent a high-level assessment of streams that are ecologically remarkable and/or have conservation value. First, we developed a state-specific indicator of at-risk aquatic species richness. We identified aquatic species designated as Species of Greatest Conservation Need (SGCN) by the Washington Department of Fish and Wildlife (Washington State Wildlife Action Plan 2015), compiled geographic range data for these species, and counted the number of at-risk species expected to be present in each stream segment. We also considered a nationwide indicator of rarity-weighted richness of critically imperiled and imperiled species (NatureServe 2013; see Appendix A). Although this indicator is not specific to aquatic species, we assume that the presence of ecologically significant streams and rivers and the unique habitats they create is a driving factor in the occurrence of higher numbers of rare species in a given area. Similarly, we consider ecosystem type rarity (see Appendix A) based on the assumption that the presence of ecologically significant streams and rivers drives the formation of unique ecosystem types. This indicator also serves as a proxy for the occurrence of “unique aquatic habitat types” in the absence of statewide data on the occurrence of specific habitat elements like peat bogs. Other aspects of ecological significance certainly exist and are likely to vary geographically across the state; we encourage *post hoc* consideration of local datasets available in a given area of interest to identify significant ecological attributes that may have been overlooked in this statewide assessment and to further target high-priority areas within rivers or watersheds prioritized by this assessment.

“Cold-water refuges” are streams where temperatures are cold enough and are projected to remain cold enough to support native cold-water species such as bull and cutthroat trout now and in the future (Isaak et al. 2015). While others have defined cold-water refuges specific to the thermal needs of individual focal species (Isaak et al. 2015), we broaden this approach to estimate the potential for a given stream to support any number of cold-water species that may be present. We do not incorporate threshold temperatures required by particular species; rather, we simply assign higher scores to streams projected to maintain colder August temperatures in the future (2080; Isaak et al. 2017).

Scaling the data. First, we rescaled all continuous values using a quantile reclassification to account for sometimes drastic differences in distributions of values. For example, one indicator may be heavily right-skewed, such that most places statewide have low values and very few places have high values, while another may be heavily left-skewed, such that most places have high values and only a few have low values. These distributions need to be equalized prior to combining them into a single score so that each contributes equally to the criterion score. We therefore reclassified them such that their reclassified values represent a percentile rank: e.g., the top 10% of values are reclassified as 0.9-1, and the lowest 10% of values are reclassified as 0-0.1, regardless of their original distribution. We then rescaled all indicators to range from 0 to 1 to ensure that each contributed equally to criteria scores. For ordinal data, we simply distributed the ordinal values evenly from 0 to 1 (Table 2).

Table 2. Rescaling ordinal indicator values for scoring ONRW potential.

Indicators	Original Values	Scaled Values
GAP status	1: Permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.	1
	2: Permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.	0.75
	3: Permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging, Off Highway Vehicle recreation) or localized intense type (e.g., mining).	0.5
	4: Included in Protected Areas Database (PAD-US), but no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout or management intent is unknown.	0.25
	0: Private land not included in the PAD-US database	0
Water quality	1: All beneficial water uses are supported	1
	2: One or more beneficial water uses are supported	0.75
	3: Unassessed water/no data	0.5
	4: Beneficial uses are not supported but a total maximum daily load (TMDL) has not been established	0.25
	5: Impaired water, TMDL established	0

Integrating indicators. We then combined indicators within a given criterion using a fuzzy algebraic sum approach (Bonham-Carter 1994; after Theobald 2013), which produced a score ranging from 0 to 1. The fuzzy sum is an increasive function in that values are, at minimum, equal to the largest contributing indicator, but never exceed 1. It is useful for combining indicators that may not be entirely independent of one another (e.g., the occurrence of rare species is partially dependent on the occurrence of rare ecosystem types) in a parsimonious way because the effects of these related quantities are not strictly additive; i.e., their combined contributions to the total criterion score level off as they approach the maximum value of 1.

Integrating criteria. After achieving a single combined score for each criterion, we simply summed those criteria scores to estimate overall ONRW potential. We used a simple unweighted sum because, in states that have formally established ONRW designation criteria, there is no language indicating that any criterion is to be given more weight than others. However, this approach lends itself to straightforward adjustment of priorities at a later time as needed by simply assigning weights to each criterion when summing their values. Above all, it is important to note that the simple unweighted summation of multiple criteria that forms the basis of our assessment here is but one of many possible prioritization schemes. Rivers that have already been designated as ONRWs were excluded from this process.

Aggregating to watersheds. Our assessment is conducted at the level of stream segments, which are defined somewhat arbitrarily by the National Hydrography Dataset (USGS 2016) as the continuous stretches between points at which tributaries join one another. These segments can thus vary drastically in length and generally do not correspond to units that one might nominate or designate as an ONRW. Aggregation of segments by stream or river name is not straightforward because stream and river names are often not unique (e.g., multiple "Smith Creeks" may occur in disparate geographies) and many segments in the NHD (USGS 2016) are unnamed. Therefore, to aggregate segment-level priority scores to meaningful units, we aggregated to HUC10 watersheds. We chose these units because they are defined consistently statewide, they have physical and ecological significance, and their size and extent are consistent with the designation of groups of streams as ONRWs elsewhere (e.g., North Fork Smith River and associated tributaries and wetlands in Oregon; all tributaries within a given wilderness area in Colorado).

A variety of methods can be applied to summarize segment-level prioritization scores across watersheds. We chose a method that answers the question: Which watersheds contain the most river miles with high ONRW potential? We calculated the total length of stream segments in each watershed that had ONRW scores in the top 25% of all segment-level scores statewide. This approach best emphasizes watersheds with many rivers and streams of high value relative to others across the state.

State Scenic Rivers

To assess state Wild & Scenic potential, we followed a similar procedure to that described for ONRW potential. We first identified existing criteria or guidelines established by the state of Washington for W&S designation. Washington has specified criteria for inclusion in the State Scenic River system (RCW 79A.55.050; Box 2). We matched each criterion to the best available spatial data with statewide coverage (Table 3), which are further described in Appendix A.

Box 2. Washington State Scenic River criteria.

Rivers of a scenic nature are eligible for inclusion in the system. Ideally, a scenic river:

*(1) Is **free-flowing without diversions** that hinder recreational use;*

*(2) Has a streamway that is **relatively unmodified** by riprapping and other stream bank protection;*

*(3) Has **water of sufficient quality and quantity** to be deemed worthy of protection;*

*(4) Has a **relatively natural setting and adequate open space**;*

(5) Requires some coordinated plan of management in order to enhance and preserve the river area; and

*(6) Has some lands along its length already in **public ownership**, or the possibility for purchase or dedication of public access and/or scenic easements.*

As seen in Table 3, there is some overlap in the indicators used to assess W&S potential and ONRW potential. Specifically, the indicators contained within the ONRW "exceptional water quality" criterion—water quality categorization, protected status of adjacent lands, and total flow and valley bottom modification—are also applied here to capture criteria 1-3 defining W&Ss. Although the ONRW and W&S designation criteria are described by different terms, we determined that the same assumptions regarding the suitability of these indicators can be applied to both. Here, primitive and unaltered rivers are expected to have high water quality unaltered by pollution and sedimentation. Lands with the highest degree of protection are expected to be the least developed and to remain so. And the degree of flow alteration and valley bottom modification is expected to provide a very direct measure of a river's primitive and unaltered state.

The requirement that potential W&Ss occur in a "relatively natural setting" with "adequate open space" is open to significant interpretation. We assumed that the intent of this criterion was intended to be distinct from criteria 1-2 ("free-flowing without diversions," "relatively unmodified"). We further assumed that the intent was likely to mirror the federal Wild and Scenic Rivers Act criteria as well as other states' criteria, which typically specify that W&S rivers should be "generally inaccessible except by trail." This criterion is distinct from the criteria used to assess ONRW potential. To assess inaccessibility (as an indicator of "natural setting and adequate open space"), we relied on a recent analysis of accessibility from major population centers based on travel time via surface transport (Weiss et al. 2018; see Appendix A for further details).

We did not consider whether lands adjacent to a stream or river are "in public ownership" within the prioritization process because we wished to support flexibility in how protected status is treated and how that status might promote different strategies for nominating and advocating for a given river's W&S designation. Instead, we include protected status information (i.e., designation type) in the streams database (see below) and encourage use of this information as a *post hoc* filter when exploring the prioritization results.

Integrating criteria. Unlike the ONRW prioritization process, we did not treat indicators related to streams' "primitive and unaltered" character as indicators or combine them using a fuzzy sum approach when assessing W&S potential. Instead, due to the smaller and simpler set of W&S criteria, we allowed each to contribute equally to the prioritization score along with our indicator of accessibility. We used a simple unweighted sum of these four indicators because, again, we had no *a priori* reason to score one criterion higher than another. However, this approach lends itself to future adjustment of weights as needed. All indicator values were rescaled as described above for ONRWs prior to summing. Rivers that have already been designated as W&Ss were excluded from this process.

Aggregating to watersheds. As described above for prioritization of ONRWs, we aggregated segment-level scores to HUC10 watersheds, using a method that answers the question: Which watersheds contain the most river miles with high W&S potential? We calculated the total length of stream segments in each watershed that had W&S scores in the top 25% of all segment-level scores statewide.

This approach best emphasizes watersheds with many rivers and streams of high value relative to others across the state.

Table 3. Indicators used to assess W&S potential for all rivers and streams in Washington. See Appendix A for details on the source data and/or derivation of these datasets.

Designation Criterion	Indicator	Data Source
Free flowing and unmodified	Total flow and valley bottom modification	Harrison-Atlas et al. 2017 (derived from NHD [USGS 2016], NID [USACE 2016], and Theobald et al. 2016)
Sufficient water quality & quantity	Assessed streams' water quality categorization (see Table 2)	Washington Department of Ecology 2014
Natural setting and open space	Accessibility from major population centers*	Weiss et al. 2018
Adjacent lands in public ownership	Protected status of adjacent lands (GAP status; see Table 2)	Protected Areas Database of the U.S. Geological Survey (PAD-US v1.4; USGS GAP 2018)

*See text for rationale

Overlay of Drinking Water Sources

To assess the degree to which ONRW and W&S priorities also serve as drinking water sources across the state, we obtained spatial data on surface water source areas for drinking water from the Washington Department of Health (Division of Environmental Health) and overlaid these polygons with our results. This dataset does not necessarily indicate that all rivers and streams within a given source area are used for drinking water. Rather, source areas represent the full extent of the watersheds contributing to surface water intakes used for drinking water. Spatial data on intake points are not publicly available for security reasons. Drinking water source areas are delineated by Washington's Source Water Assessment Program.

Database Delivery

The goal of this assessment was not only to prioritize rivers and streams for potential ONRW or W&S designation, but also to compile the data necessary to conduct these prioritizations and to assess the ecological value of rivers and streams more generally. We compiled all data used in this analysis in a geodatabase to support exploration and visualization of the priority scores and the indicators driving them, future adjustment of the prioritization results described below, and other future analyses. The database contains rescaled indicator values, criteria scores, and overall priority scores for ease of display, interpretation, and comparison. It also contains additional attributes pertinent to interpretation and filtering of the results (e.g., flow class, GAP protected status, protected lands designation type). The geodatabase and associated interactive map display are provided via Data Basin (www.databasin.org) for ease of use by those without GIS experience or access to such tools. The dataset currently has limited access, but access permission can be granted to additional users as Pew staff see fit.

Results & Discussion

Outstanding Resource Water Prioritization

Rivers and streams with high ONRW potential tended to be found in the Olympic Peninsula of northwest Washington and the Cascade Range (Map 1). High-scoring rivers and streams were also prevalent in the far northeast and southeast corners of the state (Salmo-Priest and Wenaha-Tucannon wildernesses, respectively). These high-scoring streams include extensive headwaters of major rivers, such as the Skagit, Cascade, Skykomish, and Green rivers (including both Green Rivers, i.e., tributaries of the Duwamish and the North Fork Toutle rivers). Scores were generally lower along the developed Interstate 5 corridor and in the drier, more open eastern half of the state, with the exceptions noted above. This pattern is reflected in the geographic distribution of the top-scoring 20 watersheds, which are also concentrated in the Olympic Peninsula and Cascade Range. Each of these top 20 watersheds contained at least 142 river miles that scored within the top 25% of segment-level ONRW scores (Table 4). The top-scoring watershed (Queets River, in the Olympic Peninsula) contained 277.3 river miles within the top 25% of segment-level ONRW scores.

Rivers and streams with the highest ecological value (and thus the highest potential for ONRW designation) are found in the Olympic Peninsula and the Cascade Range.

The Queets River watershed in the Olympic Peninsula contained the highest total river miles with high potential for ONRW designation across the state, as a result of its high water quality and ecological value.

Table 4. Summary of the top-scoring HUC10 watersheds across the state for ONRW potential, based on total river miles that scored within the top 25% of segment-level ONRW scores.

Rank (by miles)	Name	HUC10 ID	River miles in Top 25%
1	Queets River	1710010202	277.3
2	Satsop River	1710010401	273.9
3	Stehekin River	1702000901	259.8
4	Upper Quinault River	1710010204	245.6
5	Hoh River	1710010107	238.9
6	Elwha River	1711002005	230.9
7	Sol Duc River-Quillayute River	1710010106	210.6
8	Headwaters Lewis River	1708000201	196.8
9	Pysht River-Frontal Strait of Juan De Fuca	1711002107	179.5
10	Baker River	1711000510	177.1
11	Upper White River	1711001403	175.3
12	Wind River	1707010510	172.0

13	Upper Sauk River	1711000601	168.5
14	Clearwater River	1710010201	162.6
15	White River-Little Wenatchee River	1702001101	159.0
16	White Salmon River	1707010508	152.0
17	Lower Quinault River	1710010205	150.3
18	Gorge Lake-Skagit River	1711000507	146.1
19	Bogachiel River	1710010105	144.2
20	Icicle Creek	1702001104	142.7

Rivers and streams with high ONRW potential varied in their strengths and weaknesses (Maps 4-5). Statewide, 1,172 river miles scored in the top 10% for all ONRW objectives (water quality, ecological significance, and cold-water refuge potential), and 2,826 river miles scored in the top 25%. These rivers, found throughout the Cascades, the Olympic Peninsula, and the Wenaha-Tucannon Wilderness of southeastern Washington, are remarkable in their achievement of diverse values that often do not co-occur so strongly. A total of 603 river miles statewide scored in the top 25% for all ecological significance indicators (at-risk aquatic species diversity, rarity-weighted species richness, and ecosystem type rarity); these were primarily found in the southwest corner of the state, as well as in the Cascades along the Washington-Oregon border.

Statewide, 1,172 river miles scored in the top 10% statewide for all Outstanding Resource Water objectives—water quality, ecological significance, and cold-water refuge potential—primarily in the north Cascades; 2,826 river miles scored in the top 25% for all objectives.

A total of 603 river miles scored in the top 25% statewide for all ecological significance indicators (at-risk aquatic species diversity, rarity-weighted species richness, and ecosystem type rarity), mostly in southwest Washington.

Rivers and streams near the coast generally had very high at-risk species richness, ecosystem type rarity, and thus overall ecological value; many also had high water quality and recreation potential. Those in the Cascades also had high ecosystem type rarity, and were particularly strong in water quality and their potential to serve as cold water refugia. Although rivers in the Colville National Forest to the northeast typically had high water quality and cold-water refuge potential, they tended to have low to moderate scores in other criteria. A total of 23,376 river miles were within the ranges of at least 10 aquatic SGCN, distributed primarily across western Washington as well as the Wenaha-Tucannon Wilderness in the southeast; 3,764 river miles were within the ranges of at least 15 aquatic SGCN, almost entirely in western Washington, along with the Snake River to the southeast. Many of these high-elevation rivers and streams offer crucial thermal refuges for cold-water species. Fifteen of the top 20 watersheds overlap with drinking water source areas. Most of those in the Cascades fully overlap with drinking water sources, while those in the Olympic Peninsula generally contain only small drinking water source areas.

A total of 3,764 river miles were within the known ranges of at least 15 aquatic species of greatest conservation need, mostly in western Washington; 23,376 river miles were within the ranges of at least 10 species.

State Wild & Scenic River Prioritization

The distribution of rivers and streams with high state W&S potential differed from that of rivers with high ONRW potential, but was still primarily concentrated in the Olympic Peninsula and Cascade Range (Map 2). High-scoring rivers were clustered in the central portion of the Olympic Peninsula and the northern Cascades in particular. Low scores were ubiquitous throughout the highly developed Interstate 5 corridor and were also typical of most of eastern Washington. These patterns are again reflected in the distribution of the top-scoring 20 watersheds. Each of the top 20 watersheds contained at least 164 river miles that scored within the top 25% of segment-level W&S scores (Table 5). The highest concentration of rivers with high W&S potential was found in the Stehekin River watershed, which contained 336.4 river miles within the top 25% of segment-level W&S scores.

The Stehekin River watershed in the northern Cascades contained the highest total river miles with high potential for W&S designation across the state, as a result of its high water quality and remoteness.

Table 5. Summary of the top-scoring HUC10 watersheds across the state for W&S potential, based on total river miles that scored within the top 25% of segment-level W&S scores.

Rank (in miles)	Name	HUC10 ID	River miles in Top 25%
1	Stehekin River	1702000901	336.4
2	Upper Lake Chelan	1702000902	274.2
3	Upper Cispus River	1708000403	272.8
4	Elwha River	1711002005	249.6
5	Little Naches River	1703000201	240.9
6	Queets River	1710010202	239.3
7	Upper Quinault River	1710010204	233.5
8	Lower Chewuch River	1702000804	228.1
9	Ruby Creek	1711000505	220.8
10	Headwaters Lewis River	1708000201	219.4
11	Upper Chewuch River	1702000803	218.9
12	Headwaters Cowlitz River	1708000401	201.5
13	Ross Lake-Skagit River	1711000506	193.0
14	White River-Little Wenatchee River	1702001101	191.2
15	Gorge Lake-Skagit River	1711000507	187.1
16	Twisp River	1702000805	185.6

17	Upper Sauk River	1711000601	183.8
18	Pasayten River	1702000701	181.7
19	Hoh River	1710010107	180.6
20	Lost River	1702000801	164.8

Just 316 river miles scored in the top 10% statewide for all indicators of State Scenic River potential, including free flowing and unmodified; water quality and quantity; natural, open setting; and public land adjacent. A total of 3,397 river miles scored in the top 25% statewide, primarily in the Olympic Peninsula and north Cascades.

Rivers and streams with high W&S potential were consistently characterized by both high water quality and high inaccessibility by surface transport, one indicator of naturalness and openness alongside degree of valley bottom modification (Map 5a, d). A total of 316 river miles scored in the top 10% statewide for all indicators of State Scenic River potential (free flowing and unmodified; water quality and quantity; natural, open setting; and public land adjacent), while 3,397 river miles scored in the top 25% statewide for all indicators. These rivers were more tightly clustered in the Olympic Peninsula and north Cascades than those meeting all ONRW criteria. Eighteen of the top 20 watersheds overlapped drinking water sources, though only partial overlap occurred in top watersheds located in the Olympic Peninsula.

Fifteen of the top 20 ONRW watersheds and 18 of the top 20 W&S watersheds overlapped with drinking water source areas.

Potential Applications of the Data and Results

These analyses were intended to support scientifically grounded identification of ONRW and W&S candidates with the greatest potential for designation. Specifically, we aimed to provide scientific information quantifying the ecological value and thus the positive ecological impacts of potential designations. Here we have demonstrated the application of these results to identifying watersheds containing the best candidates for ONRW and W&S designation statewide. However, our prioritization results and the underlying database supporting them can be applied in a variety of ways.

First, the results and database could be used to identify the best candidates for conservation (whether by ONRW or state W&S designation or by other means, e.g., federal Wild and Scenic) within a smaller region of interest. For example, if planning efforts are focused on a region that did not contain any of the highest-priority streams or watersheds (e.g., Upper Crab-Wilson, Lower Yakima water resource inventory areas), our results could be used to identify the best candidates *within the focal region alone.* The database may show that these candidates have, for example, lower diversity of rare species and habitats than other parts of the state, but still have high water quality and minimal human modification, making them worthwhile targets for protection. For example, the rivers and streams surrounding the Turnbull National Wildlife Refuge in eastern Washington have high water quality and are expected to support habitat for Columbia spotted frog (*Rana luteiventris*), Northern leopard frog (*Lithobates pipiens*), and tiger salamander (*Ambystoma tigrinum*), which are not found in the higher-scoring watersheds of western Washington. Similarly, tributaries of the Snake and ultimately of the Columbia River that flow through the southeastern corner of the state—especially in the Umatilla National Forest—serve as important spawning and rearing grounds for bull trout (*Salvelinus confluentus*) and white sturgeon (*Acipenser transmontanus*) and afford an important migration corridor for chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) as they migrate farther inland to spawn.

The results can also be used to assess the ONRW or W&S potential of a specific river or watershed of interest. This may be useful for supporting existing grassroots efforts to protect a given river or watershed, to bolster other localized, place-based information, or to respond to local or regional conservation opportunities as they arise. Relatedly, the database can be used to identify the criteria and indicators that are strengths and weaknesses in a given place.

Additionally, filters can be applied to the database to identify all streams and rivers that meet a threshold ONRW or W&S score, that meet a threshold for a particular criterion of interest (e.g., cold-water refuge potential, Map 6), or that may qualify for both ONRW and W&S designation. Similarly, filters could be used to select and explore only rivers occurring within wilderness areas or meeting a particular flow volume threshold. The complete database provides many opportunities to adapt the information to a variety of needs and purposes.

We highlight only a handful of major applications of the results and data here, but others surely exist. For example, criteria scores could be recombined using weighted sums to reprioritize rivers with greater or lesser emphasis on particular criteria, additional datasets could be added to represent particular user interests or as new information becomes available, or the data could be used to assess restoration potential (i.e., where water quality or flow modification might be detracting from otherwise high ecological values).

Limitations of the Data and Results

We compiled the most robust data available to us at statewide extents and co-developed a transparent, flexible means of scoring ONRW and W&S potential. However, our analyses and the underlying data do have limitations.

First, our analysis is intended as a coarse-filter, first-pass identification of potential priorities. Consideration of finer-scale, local information and circumstances is needed before taking policy or on-the-ground actions to protect high-scoring rivers. This is due in part to the coarse spatial or thematic resolution of some of the data available for our analyses. For example, our estimate of at-risk aquatic species richness is based on species range data that typically have spatial resolution of HUC8 watershed units or counties. Thus, we can predict the potential presence of a given species of greatest conservation need in a given stream from state-level data, but local-scale information—including expert opinion—should subsequently be considered to confirm the presence of the species of interest in a particular stream. Similarly, we assume that streams with cooler projected August temperatures are most likely to offer cold water thermal refuges to cold-water species, but it is necessary to consult fish distribution data and species-specific physiological temperature thresholds to determine whether a given stream of interest is likely to serve as a refuge for a particular species of concern (Isaak et al. 2015).

Second, we used a simple prioritization method that achieves transparency in the results, supports communication around the process, and enables the flexibility to make future adjustments. However, our use of this approach means that our results do not offer an optimized suite of priorities that maximize ecological benefits, minimize costs or risks, and achieve balanced representation across designation criteria. There are inherent tradeoffs between our chosen approach and the use of more complex spatial optimization algorithms. We determined that use of a simple objective hierarchy best fit the stated needs (i.e., transparency, ease of communication, flexibility) and that a more complex optimization approach did not. Furthermore, the data necessary to maximize benefits of an optimization approach (i.e., costs and risks associated with protection of a given river or watershed) were not available to us statewide. Nevertheless, it is important to be aware of what this analysis does not do and was not intended to do.

Third, our prioritization and underlying database are not (nor are they intended to be) a one-size-fits-all solution. This work was focused on statewide identification of rivers and streams with the highest potential for ONRW or W&S designation. Other similar efforts may exist at different scales (e.g., Trout Unlimited assessment of W&S eligibility in the Rogue River basin of Oregon); these efforts will likely differ in their approach and findings due to differences in data availability across these extents or differences in objectives. Likewise, other opportunities for river protection outside of ONRW or W&S designation are available that may be defined by different criteria or consider additional tradeoffs. Our findings are meant to be interpreted and applied in the context of other complementary information offered by other researchers and conservation efforts. This may include local-scale data or other contextual information (e.g., local community and political support) that may help to narrow down a feasible set of priorities that diverse partnerships can agree to support.

Finally, it is critical to acknowledge that ongoing climatic changes will continue to have direct and dramatic implications on freshwater systems in Washington and elsewhere in the American West. This is particularly true for watersheds that have historically been snow-dominant, but that are projected to transition to rain-dominance (Barnett et al. 2005). The resulting changes and variability associated with the magnitude, frequency, duration, and timing of river flows are not incorporated in this prioritization scheme but certainly warrant consideration in evaluating how well ONRW designation may afford protection in a warming world.

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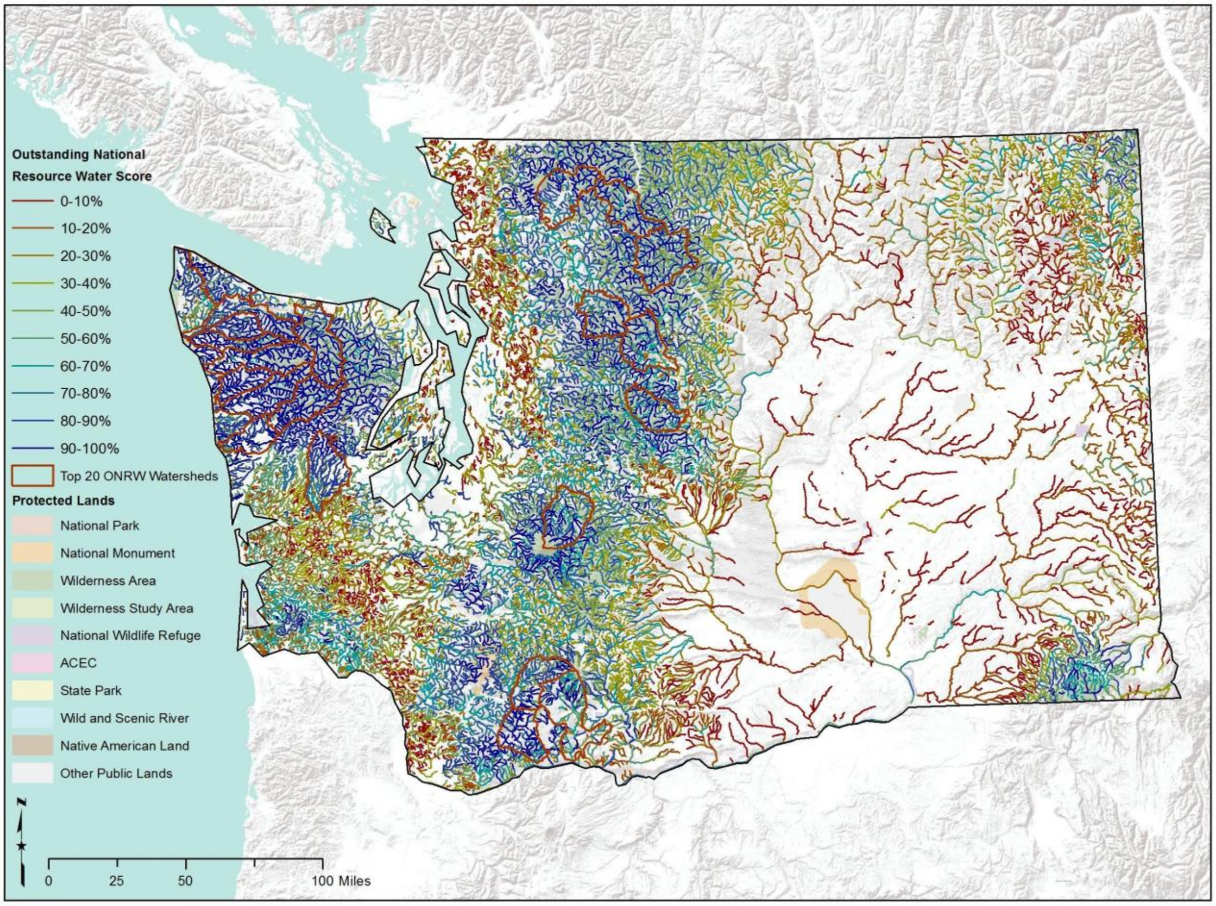
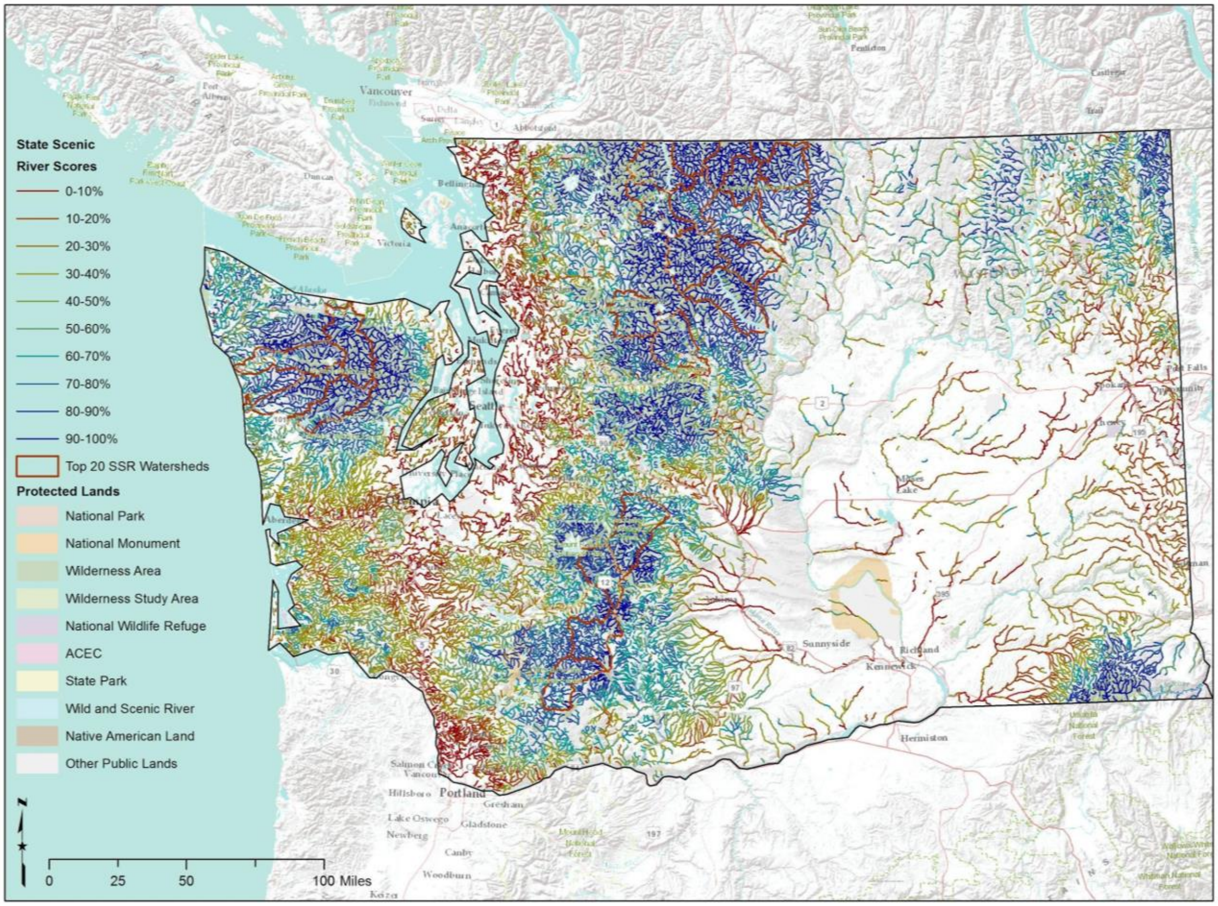
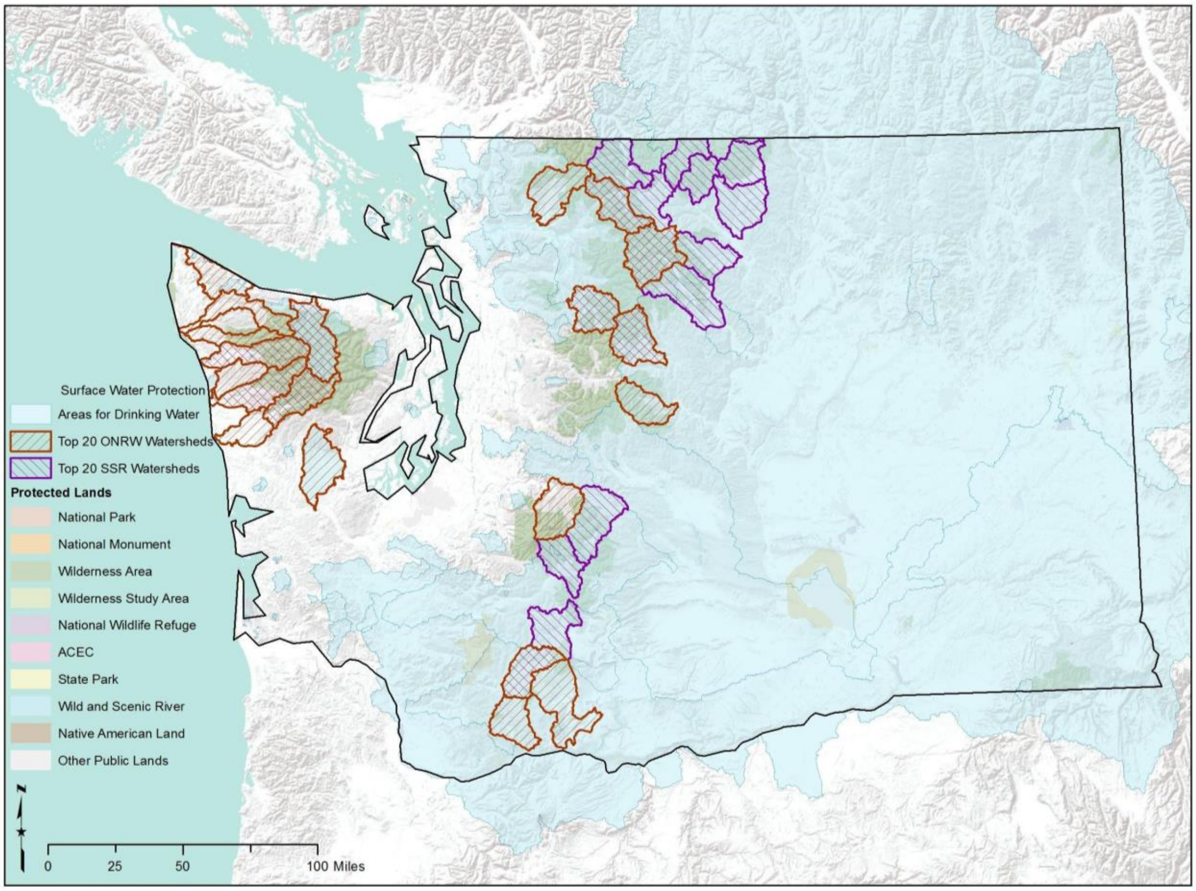
Maps



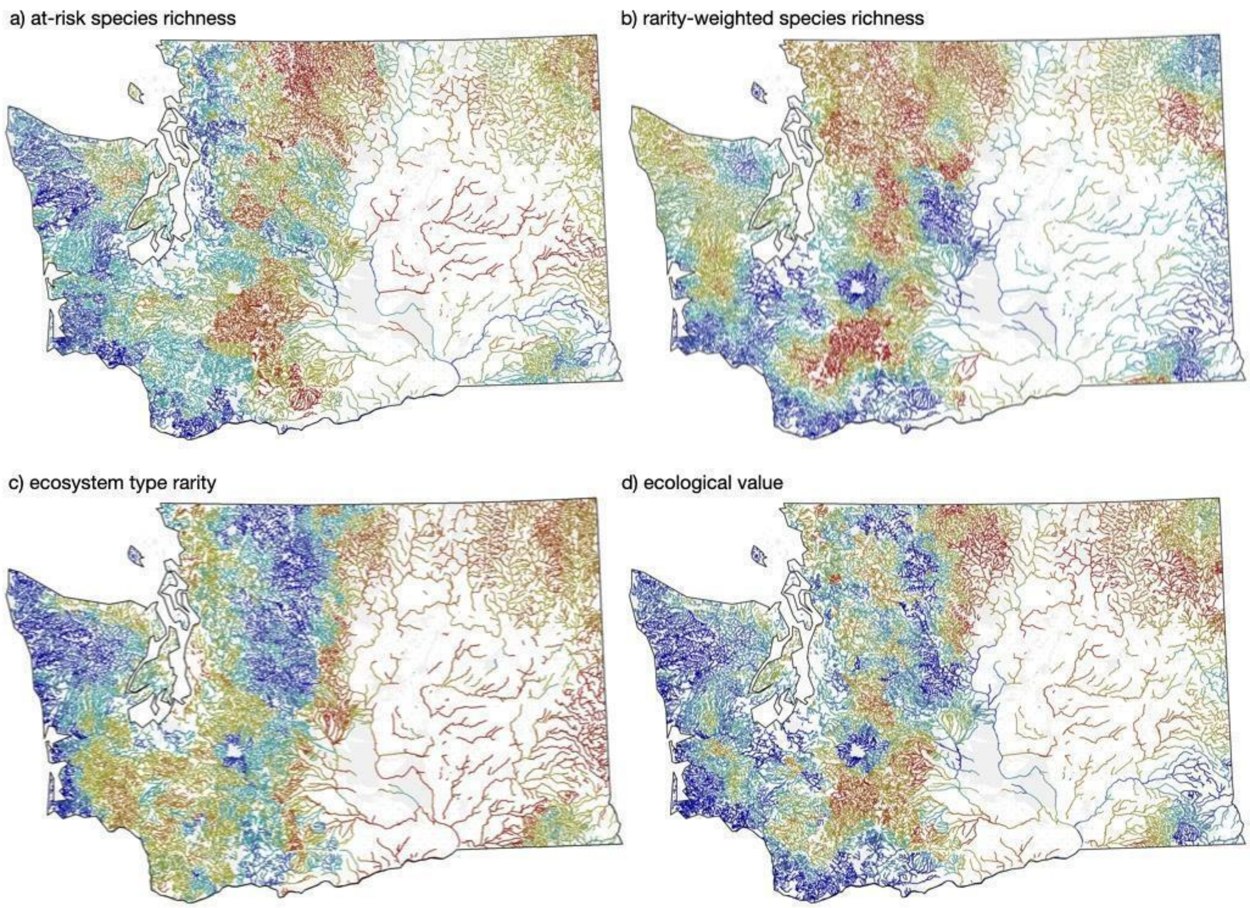
Map 1. Map of segment-level Outstanding National Resource Water (ONRW) scores highlighting top 20 watersheds.



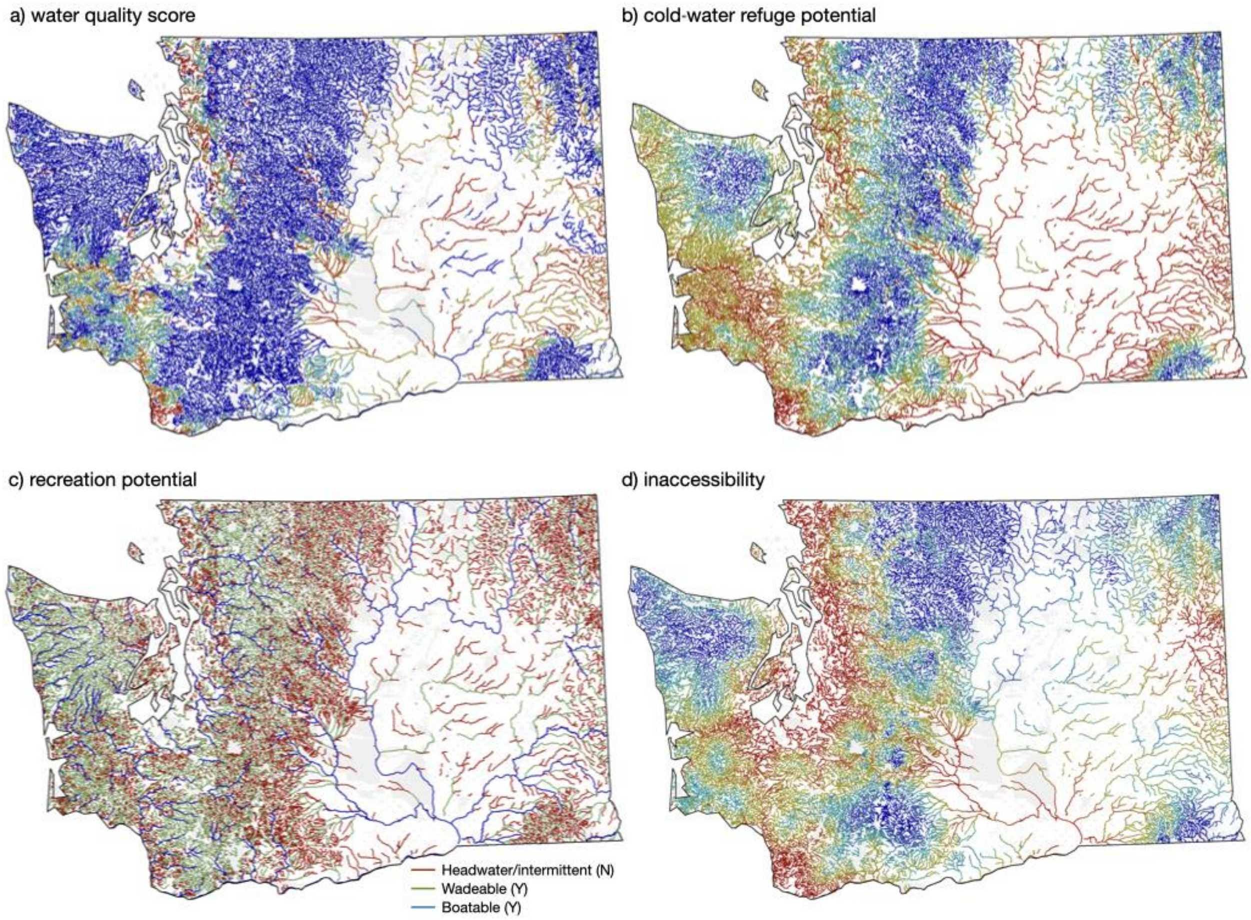
Map 2. Map of segment-level state Wild & Scenic River (W&S) scores highlighting top 20 watersheds. These are termed State Scenic Rivers (SSR) in Washington.



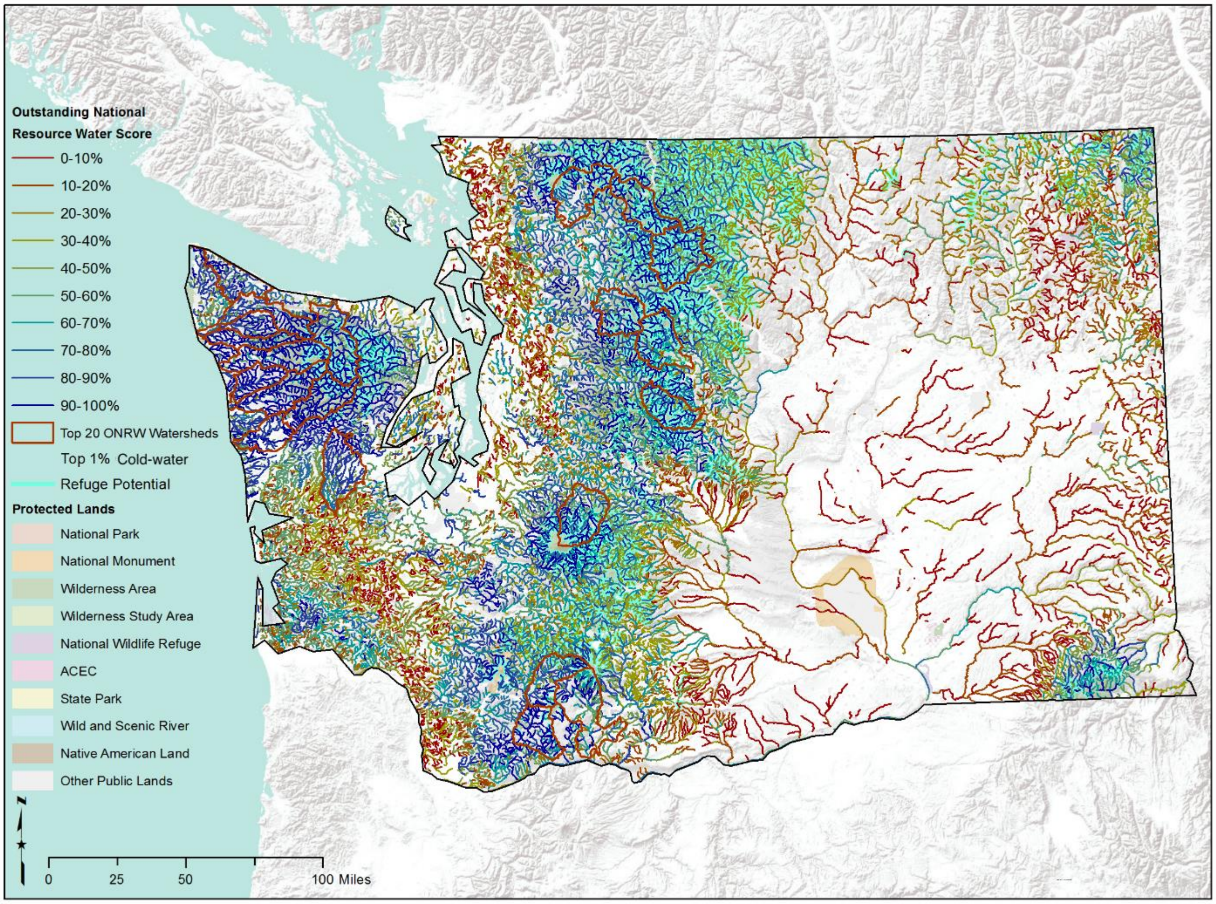
Map 3. Map of top 20 watersheds for ONRW (red) and W&S (purple) designation, overlaid on surface drinking water source watersheds. Note that watersheds scoring in the top 20 for both ONRW and W&S potential appear with crosshatching.



Map 4. Maps of a) at-risk species richness, b) rarity-weighted species richness, c) ecosystem type rarity, and d) ecological value, scored as the fuzzy sum of a, b, and c, across Washington. In each map, values are quantile scaled such that the highest-scoring 10% of stream segments are shown in dark blue and the lowest-scoring 10% are shown in red.



Map 5. Maps of a) water quality score (calculated as the fuzzy sum of water quality category, GAP protected status, and total degree of modification), b) cold-water refuge potential, c) potential recreational value, and d) inaccessibility across Washington. In each map (except (c)), values are quantile scaled such that the highest-scoring 10% of stream segments are shown in dark blue and the lowest-scoring 10% are shown in red.



Map 6. Map of segment-level Outstanding Resource Water scores, with top 1% of cold-water refuge scores highlighted in turquoise, demonstrating one example of application of additional *post hoc* filters to identify river and stream segments that best support particular protection targets.

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Appendix A. Derivation of Indicators

Descriptions of source data and derivation methods for indicators used to assess Outstanding National Resource Water (ONRW) and state Wild & Scenic River (W&S) criteria across Washington.

At-risk aquatic species richness. The at-risk aquatic species richness score represents the number of aquatic Washington Species of Greatest Conservation Need (SGCN; Washington Department of Fish & Wildlife 2015) potentially present in a given river or stream. Species range data were obtained from the Western Division of the American Fisheries Society via Data Basin (WDAFS 2012) at HUC8 resolution and from U.S. Fish and Wildlife Service species profiles (variable resolution; USFWS 2019). Ranges were overlaid and counted, then counts were percentile scaled (i.e., a score of 0.9 indicates that on average over its length, the segment is within the geographic range of more SGCN than 90% of other segments across Washington). Rivers and streams in watersheds with high at-risk species richness are likely to support fish, amphibians, reptiles, and/or invertebrates that the state has designated as SGCN.

Rarity-weighted species richness. Rarity-weighted species richness provides a relative measure of the concentration of rare and irreplaceable species across the U.S. (Chaplin et al. 2000). High rarity-weighted species richness is often indicative of the presence of numerous endemic species and/or sites that contain critically imperiled or imperiled species with restricted distributions (i.e., G1-G2 –ranked species). These sites are essential for maintaining species diversity, particularly rare, sensitive, and irreplaceable species. We used NatureServe's rarity-weighted richness index of critically imperiled (G1) and imperiled (G2) species (refreshed 2013) 1-km resolution data layer as an indicator of species rarity and irreplaceability (see Chaplin et al. 2000 for references and description of methods). Additional information on this metric is available here.

Ecological system type rarity. Areas with high ecological system rarity are those that support rare, unique, or irreplaceable natural systems. These systems are likely to consist of species that are rare, unique, or irreplaceable. Ecological systems are defined as "groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates and/or environmental gradients" (Comer et al. 2003), thus they incorporate physical components such as landform position, substrates, hydrology, and climate in addition to vegetation. To characterize ecological system type rarity, we calculated the areal extent of USGS GAP ecological system types at 30-m resolution (USGS 2011), then normalized the values based on the maximum value so that they ranged from 0 (least rare) to 1 (most rare).

***Cold-water refuge*.** Cold-water refuge potential was estimated based on projected stream temperature (Isaak et al. 2017). We assumed that streams with colder projected mean August temperatures in 2050 are most likely to continue to provide habitat for cold water dependent species into the future. Thus assumption was based on the approach of Isaak et al. (2015), but our approach was generalized to multiple cold water dependent species (i.e., it is independent of species-specific temperature thresholds).

Absence of human modification. Harrison-Atlas et al. (2017) quantified the total degree of modification of rivers and streams in the western U.S. by considering both flow modification due to upstream barriers and modification of the adjacent valley bottom (or flood plain) by human activities such as agriculture, transportation, and residential development. We percentile scaled this integrated estimate (i.e., a score of 0.9 indicates that on average over its length, the segment has lower modification than 90% of other segments across Washington). Watersheds with high scores have near-natural levels of flow due to absence of dams and diversions upstream and flow through mostly intact valley bottoms with little alteration for human use.

Water quality. Water quality was categorized by the Washington Department of Ecology (2019) for assessed streams and rivers such that: 1 = all designated water uses are supported; 2 = some but not all designated uses are supported; 3 = insufficient data are available to make a determination; 4 = not all designated uses are supported but a total maximum daily load (TMDL) designation is not required because a) it has already been completed, b) other control measures are expected to result in attainment of supported use, or c) the impairment is not caused by a pollutant; and 5 = impaired, such that not all designated uses are supported and a TMDL has been identified. These ordinal values were rescaled 0-1 as described in Table 2 for integration into ONRW and W&S prioritization scores. A water quality score was developed to fill gaps in water quality information for streams that have not yet been assessed. This proxy was calculated as a fuzzy sum of the rescaled water quality category (where available), rescaled GAP protected status (Table 2), and total degree of modification, then percentile scaled (i.e., a score of 0.9 indicates that on average over its length, the segment is expected to have higher water quality than 90% of other segments across Washington).

Recreation potential. Due to the absence of consistent, inclusive statewide data on recreation value of rivers and streams, we relied on a coarse proxy for recreation potential, which indicates whether a river or stream has sufficient mean annual flow to support recreational activities such as swimming, fishing, boating, and rafting (Harrison-Atlas et al. 2017). A value of 1 indicates that the river has sufficient flow to be considered "wadeable" or "boatable" (i.e., > 6 cubic feet per second). This should be considered an initial screen for potential recreational value; local datasets and information should be consulted for additional details pertaining to recreational opportunities and/or use.

Accessibility. Weiss et al. (2018) quantified and validated global accessibility to high-density urban centers at a resolution of 1 km for 2015, as measured by travel time via surface transport. They first completed a global-scale synthesis of two leading roads datasets—Open Street Map (OSM) data and distance-to-roads data derived from the Google roads database. They then integrated 10 global-scale surfaces that characterize factors affecting human movement rates and 13,840 high-density urban centers to quantify and map travel time to cities using a least-cost path algorithm (Dijkstra 1959). Weiss et al. (2018) aimed to quantify inequities in access to the human goods and services that are heavily concentrated in cities and to highlight needs for increasing accessibility to meet Sustainable Development Goals established by the United Nations. However, their analysis is equally useful for quantifying the inverse property of landscapes—inaccessibility—associated with the remote, undisturbed places of interest here. Here, values are percentile scaled (i.e., a score of 0.9 indicates that on average over its length, the segment is more inaccessible than 90% of other segments across Washington).

Appendix B. Detailed prioritization methods

Score calculations below are performed using the flowlines shapefile (common to all statewide flowline layers in the map) contained in the map package associated with this report (WA_StateOfOurRivers_data.mpk). Most relevant fields have already been prepared and scaled appropriately for prioritization as described in the methods section above, except as noted below. For most steps, and unless otherwise noted, simply add a new field (type: double) and use the Field Calculator in ArcMap (10.8) to generate the field's values.

ONRW analysis

1. Rescale categorical variables (water quality category and GAP protected status) as described in Table 2 (above) for use in score calculation. Note: If segments have a water quality category value of 0 or NoData, they should be rescaled to a value of 3 (corresponding to "unassessed/no data").

2. Assign a recreation potential score (RecScore) based on SizeClass (if SizeClass > 1, RecScore = 1, otherwise RecScore = 0).

3. Calculate the ecological significance criterion score as the fuzzy sum of ecological indicators (Bonham-Carter 1994; after Theobald 2013). Field names are defined and described in the accompanying attribute definitions documents.

   EcoScorePerc = 1 - [(1 - SGCNRichPerc) * (1 - RWRichPerc) * (1 - EcoRarPerc)]

4. Calculate the water quality proxy score as the fuzzy sum of water quality and additional relevant proxies:

   WQScorePerc = 1 - product(1 - WQCat_scaled[1], 1 - GapStatus_scaled[1], 1 - HumModPerc)

   [1]*Rescaled as described in step 1*

5. Rescale the ecological significance and water quality scores above to percentile scores. To do this in ArcGIS:
   a. Convert polylines to raster format (90 m resolution).
   b. Use the Slice tool (equal area method, 100 zones) to redistribute values as percentile ranks. Note: Depending on the distribution of the raw values, it may not be possible to create 100 equal-area zones. If this is the case, create the maximum possible number of zones given the distribution.
   c. Use Zonal Statistics as Table to extract the mean raster value intersected by each flowline segment (zone data = original flowlines, zone = FID, value raster = the sliced raster created in step b, statistics type = MEAN).
   d. Rescale values to 0-1 by dividing by the maximum value.
   e. Join values back to the working flowlines attribute table by FID; rename the joined fields EcoScorePerc and WQScorePerc.

6. Calculate the ONRW potential score for each stream segment as simply the sum of all relevant criteria (differential weights could be applied at this step in the future, but for purposes of this analysis, equal weights were used). Then rescale the ONRW potential score to 0-1 for easier interpretation by dividing by the maximum value (4).

   ONRWSegMean = EcoScorePerc + WQScorePerc + RecScore + ColdwaterPerc

7. Aggregate segment-level scores to HUC10 watersheds:
   a. Select and export the top 25% of segment-level ONRW scores as a new shapefile.
   b. Sum the length of these top-scoring segments in each watershed using the Summarize tool on the HUC10 field in the exported top 25% flowlines attribute table. Choose the sum of Length_mi as the summary statistic to be included.
   c. In the resulting summary table, sort the summed length field in decreasing order, then select and export the top 20 HUC10 units.
   d. Join the summed length field in the summary table back to the full working flowlines dataset by HUC10 to produce the ONRWHUC25perc field (aggregated watershed-level score).

<u>Wild & Scenic analysis</u>

1. The state Wild & Scenic potential score is a simple sum of the relevant indicators. As in step 5 above for ONRW scores, differential weights could be applied at this step in the future, but for purposes of this analysis, equal weights were used.

   WSSegMean = WQScorePerc + GapStatus_scaled[1] + HumModPerc + AccessPerc

   [1]*Rescaled as described in step 1 of the ONRW analysis*

2. Rescale the result to 0-1 for easier interpretation by dividing by the maximum possible value (4).

3. Aggregate segment-level scores to HUC10 watersheds as described in step 7 of the ONRW analysis. This will generate the top 20 HUC10 units for W&S scores as well as the WSHUC25perc aggregate score field.

<u>Generating reported summary statistics</u>

1. To identify the total number of river miles meeting a given threshold for multiple criteria:
   a. Perform a selection by attributes. For example, to select segments within the top 25% of all ecological indicator scores, use the following selection query:

      "SGCNRichPerc" >= 0.75 AND "RWRichPerc" >= 0.75 AND "EcoRarPerc" >= 0.75

b. Use the Statistics function in the drop-down menu on the Length_mi field to identify the total river mileage of the selected segments.

2. To identify the total number of river miles expected to support a given number of Species of Greatest Conservation Need (SGCN):
    a. Select features of the Raw SGCN Counts layer that have a Join_Count greater than the target number of species (e.g., 30).
    b. Perform a selection by location. Select features from the flowlines dataset that intersect the selected Raw SGCN Counts features.
    c. Use the Statistics function in the drop-down menu on the Length_mi field to identify the total river mileage of the selected segments.

3. To identify the number of top 20 HUC10 watersheds that contain drinking water sources, perform a selection by location. Select top 20 HUC10 watersheds that intersect the drinking water source areas layer.

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