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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. Our aim is not to set goals for specific protections in New Mexico, but rather to offer a concrete, science-driven basis for consideration of a number of mechanisms of protection. We focused in particular on identifying rivers and streams throughout New Mexico with the highest potential for Outstanding National Resource Water (ONRW) 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 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 30,295 miles considered, rivers and streams with the highest ONRW potential are distributed throughout the state, but most often coincide with national forest lands. A total of 583 river miles demonstrate outstanding overall value in that they score in the top 25% of segment-level ONRW scores statewide for every ONRW criterion, including water quality, ecological significance, and recreation potential, attributes that do not coincide as strongly elsewhere. Similarly, 248 river miles are remarkable in scoring in the top 25% of river segment scores statewide for all indicators of ecological significance, including at-risk aquatic species diversity, rarity-weighted species richness, and ecosystem type rarity. New Mexico’s rivers support a variety of aquatic species identified by the state as Species of Greatest Conservation Need (SGCN); 5,453 river miles are within the ranges of at least five aquatic SGCN, and 1,121 river miles are within the ranges of at least 10 at-risk aquatic species. Four of the top 20 watersheds for ONRW designation contain drinking water sources; protection of these waters would help to maintain provision of this vital ecosystem service for generations to come. At the watershed level, the Gallinas Canyon-Mimbres River watershed in the Gila National Forest is extraordinary in that it contains the greatest total river miles (174 miles) with high ONRW potential in a single watershed.

In short, hundreds of river miles across New Mexico—particularly in and adjacent to New Mexico’s national forests—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 New Mexico that can inform and support efforts to ensure those values persist.

Introduction

Rivers are the lifeblood of our wildlands. 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); surface waters provide clean drinking water and support other domestic uses for two-thirds of the United States population (CDC 2009, EPA 2007); they offer a wealth of recreation opportunities; and they offer myriad other ecosystem services supporting ecological and human health and well-being (e.g., fisheries, climate regulation, aesthetic enjoyment; Brauman et al. 2007).

As our planet warms and climate patterns change (IPCC 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 a 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% percent 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 New Mexico with the highest potential for Outstanding National Resource Water (ONRW) designation, especially due to their ecological value. 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 New Mexico, approximately 800 miles have been designated ONRW. While other means of achieving river protection exist, (e.g., the federal Wild and Scenic Rivers Act, designation of state scenic or recreational river areas, other state legislative or administrative protections), 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 & 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. 2011). 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 designation (as a proxy for rivers deserving and capable of one or more forms of protection) 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), to score ONRW potential. This framework 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 the hierarchy (e.g., top tier of Fig. 1) was to identify the rivers and streams with the highest potential for ONRW designation. This objective was further defined by multiple designation criteria, which formed the second tier of the hierarchy (as in Fig. 1). Finally, the degree to which each river or stream achieved each criterion was assessed based on one or more indicators, which were defined by the available data. These criteria, indicators, and the weights assigned to each to achieve priority scores are described in detail below.

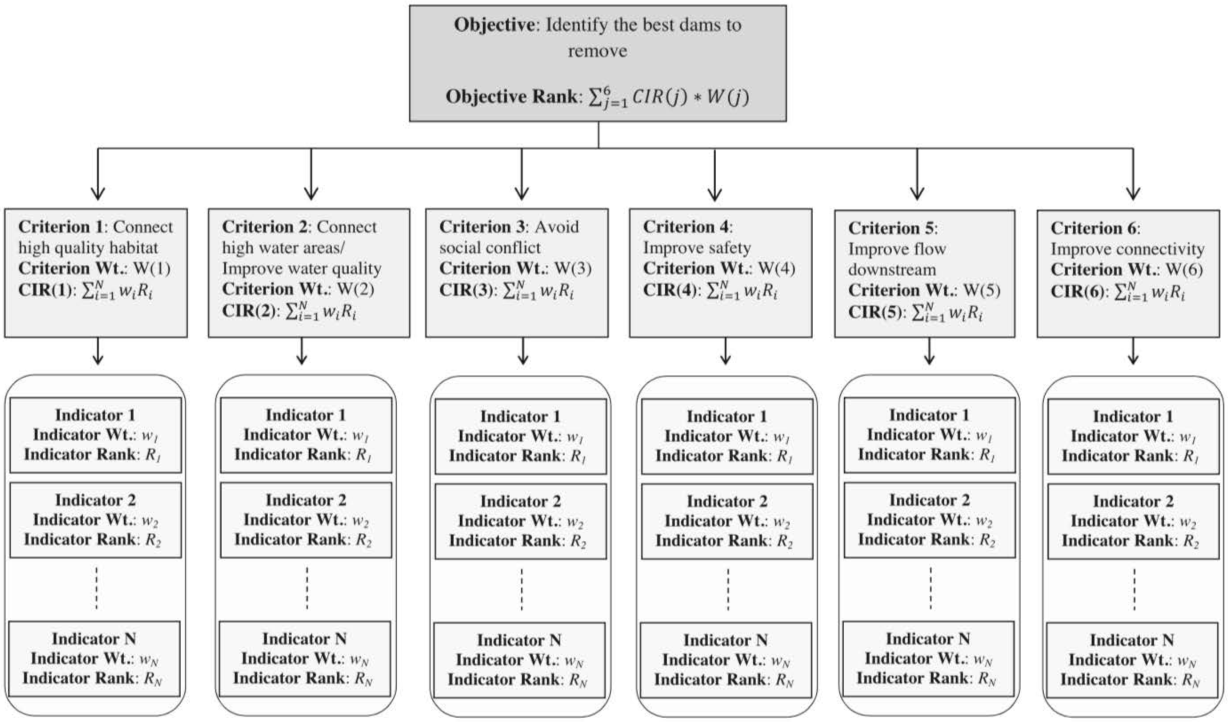

Figure 1. Example of an objective hierarchy framework, in which weighted indicators are used to assess the extent to which criteria defining an overall objective are met. In this example, the framework is used to identify the best dams for removal to achieve ecological and social benefits (Hoenke et 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; U.S. 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—of 30,295 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 National Resource Waters

To score ONRW potential, we first identified existing criteria or guidelines established by the state of New Mexico for ONRW designation. New Mexico has established formal criteria for designation (N.M. Code R. § 20.6.4.9; see 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. New Mexico Outstanding National Resource Waters criteria (N.M. Code R. § 20.6.4.9).

A surface water of the state, or a portion of a surface water of the state, may be designated as an ONRW where the commission determines that the designation is beneficial to the state of New Mexico, and:

1. the water is a **significant attribute of** a state special trout water, national or state park, national or state monument, national or state wildlife refuge or designated wilderness area, or is part of a designated wild river under the federal Wild and Scenic Rivers Act;

2. the water has **exceptional recreational** or **ecological significance**; or

3. the existing **water quality** is equal to or better than the numeric criteria for protection of aquatic life and contact uses and the human health-organism only criteria, and the water **has not been significantly modified by human activities** in a manner that substantially detracts from its value as a natural resource.

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

Designation Criterion	Indicator	Data Source
Recreational significance	Sufficient mean annual flow to support wading and/or boating	Harrison-Atlas et al. 2017 (derived from NHD [USGS 2016])
Ecological significance	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
Exceptional water quality, absence of modification	Assessed streams water quality categorization (see Table 2)	New Mexico Environment Dept. 2018
	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)
Attribute of protected lands*	Designation type	Protected Areas Database of the U.S. (PAD-US v1.4; USGS GAP 2018)

**Did not contribute numerically to ONRW potential score; see below*

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., having 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 & 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 by the New Mexico Department of Fish and Wildlife (NMDGF 2019), 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. 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.

To quantify “exceptional water quality,” we first obtained water quality data from the New Mexico Environment Department (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, we supplemented this dataset with water quality proxies that are available statewide. We considered the protected status of the lands through which the stream passes (using PAD-US v1.4; USGS GAP 2018), under the assumption that waters passing through lands with higher degrees of protection are more likely to be in good condition (Johnson and Spildie 2014). To capture the degree to which streams are "modified by human activities," 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).

Aside from including GAP protected status as one proxy for water quality (above), we did not consider whether a stream is "a significant attribute of" protected lands as part of our ONRW prioritization score because we wished to support flexibility in how protected status is considered and how that status might promote different strategies for nominating and advocating for a given river's ONRW designation. Instead, we include protected status information in the streams database (see below) so that it can be used as a *post hoc* filter when exploring the prioritization results.

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, including GAP protected status levels established by USGS GAP (2018) and water quality ordinal ranks established by the New Mexico Environment Department (2018).

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. Still, 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.

Overlay of Drinking Water Sources

To assess the degree to which ONRW priorities also serve as drinking water sources across the state, we obtained spatial data on drinking water intakes from the Drinking Water Bureau of the New Mexico Environment Department. Intakes are represented as points associated with permits for public water utilities. Because these points do not fully capture the extent of surface drinking water sources, we identified the HUC10 units containing one or more intake points, then overlaid these polygons with our results. However, it should not be assumed that all rivers and streams within a given source watershed are used for drinking water.

Database Delivery

The goal of this assessment was not only to prioritize rivers and streams for potential ONRW designation, but also to compile the data necessary to conduct this prioritization 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 National Resource Waters

Rivers and streams with high ONRW potential are distributed across the state, most often on national forest lands, including the Carson, Gila, and Lincoln national forests (Map 1). Scores were generally lower on the Navajo Nation, in the Albuquerque area, and at the eastern border of the state. This pattern is reflected in the geographic distribution of the top-scoring 20 watersheds, which generally contain or are adjacent to national forest lands in the north-central, south-central, or southwest portions of the state. Each of these top 20 watersheds contained at least 70 river miles that scored within the top 25% of segment-level ONRW scores (Table 3). The top-scoring watershed (Gallinas Canyon-Mimbres River in the Gila National Forest) contained 173.8 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 generally found on or adjacent to national forest lands.

Table 3. 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	Gallinas Canyon-Mimbres River	1303020201	173.8
2	Rio Ruidoso	1306000801	163.4
3	Upper Rio Penasco	1306001003	150.7
4	Bitter Creek	1305000311	123.2
5	Lincoln Canyon	1306000901	115.4
6	Embudo Creek	1302010109	114.4
7	Chavez Creek	1302010201	113.7
8	Tularosa Creek	1305000312	108.5
9	Abiquiu Reservoir	1302010210	106.0
10	Costilla Creek	1302010101	105.9
11	Headwaters Pecos River	1306000102	104.2
12	Upper Jemez River	1302020202	98.9
13	Rio Guadalupe	1302020201	97.8
14	Cottonwood Creek	1305000305	97.2
15	Elk Canyon	1306001001	94.7
16	Rio San Antonio	1301000503	89.4
17	Rio Bonito	1306000802	84.0
18	Red River	1302010103	79.3
19	Hasperos Canyon	1306000502	73.1
20	Cow Creek	1306000101	70.7

Rivers and streams with high ONRW potential varied in their strengths and weaknesses (Maps 3-4). In total, 583 river miles scored in the top 25% statewide for all ONRW objectives (water quality, ecological significance, and recreation potential), and 166 river miles scored in the top 10%. These rivers are remarkable in their achievement of high scores for multiple attributes that often do not co-occur so strongly. These rivers and streams were not clustered in any particular geography and were instead distributed widely throughout the state. A total of 248 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 segments were found in a mix of public lands across the southern half of the state (e.g., national forest, Bureau of Land Management grazing allotments, state trust lands).

In total, 583 river miles scored in the top 25% statewide for all Outstanding National Resource Water objectives, including water quality, ecological significance, and recreation potential, and were widely distributed.

A total of 248 river miles scored in the top 25% statewide for all indicators of ecological significance, including at-risk aquatic species diversity, rarity-weighted species richness, and ecosystem type rarity, distributed across southern New Mexico.

Rivers and streams in the Lincoln National Forest had consistently high at-risk species richness, ecosystem type rarity, and thus overall ecological value. Similarly, the Pecos River and tributaries scored highly due to at-risk aquatic species richness and rarity-weighted species richness. Many rivers and streams in both areas had recreation potential based on mean annual flow but suffered from lower water quality. High ecosystem type rarity and fairly high at-risk aquatic species richness conferred high ecological value to rivers and streams of the Carson National Forest and surrounds, as well. In the southwest, including the Gila National Forest, scores for all ecological criteria were generally high. A total of 5,453 river miles were within the ranges of at least five aquatic SGCN, distributed throughout southern New Mexico, while 1,121 river miles were within the ranges of at least 10 aquatic SGCN, found in the Gila National Forest and the southern portion of the Pecos River. Four of the top 20 watersheds contain drinking water sources, all of which are in or adjacent to the Lincoln National Forest.

A total of 1,121 river miles were within the known ranges of at least 10 aquatic species of greatest conservation need, all in western New Mexico; 5,453 river miles were within the ranges of at least five species, distributed throughout southern New Mexico.

Four of the top 20 watersheds contain drinking water sources, all of which are in or adjacent to the Lincoln National Forest.

Potential Applications of the Data and Results

These analyses were intended to support scientifically grounded identification of ONRW 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 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 designation or by other means) 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., Lower Colorado, Upper Gallinas and Pecos basins), 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. Likewise, a river that does not boast high diversity may still provide important habitat for at-risk species with limited distributions. For example, Salt Creek and its tributaries in the Tularosa Basin scored fairly low overall, but have unimpaired water quality and are expected to support at-risk Gila chub (*Gila intermedia*) and White Sands pupfish (*Cyprinodon tularosa*), which are generally not found elsewhere in the state (USFWS 2015; White Sands Pupfish Conservation Team 2006).

The results can also be used to assess the ONRW 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 score or that meet a threshold for a particular criterion of interest (e.g., water quality). 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 (e.g., state scenic or recreational river areas, other state legislative or administrative protections). 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 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.

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. Further, our approach does not indicate the “return on investment” that designations within the top watersheds may yield. For example, many top-scoring watersheds happen to lie within protected areas and so rivers and streams therein are already inherently afforded a degree of protection. 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. Nor are these results intended to serve as a road map for pursuing specific ONRW protections. This work was focused on statewide identification of rivers and streams with the highest potential for ONRW designation. Other similar efforts may exist at different scales (e.g., Trout Unlimited assessment of state scenic waterway eligibility in Oregon’s Rogue River basin); 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 designation are available that may be defined by different criteria or consider additional trade-offs. 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 New Mexico 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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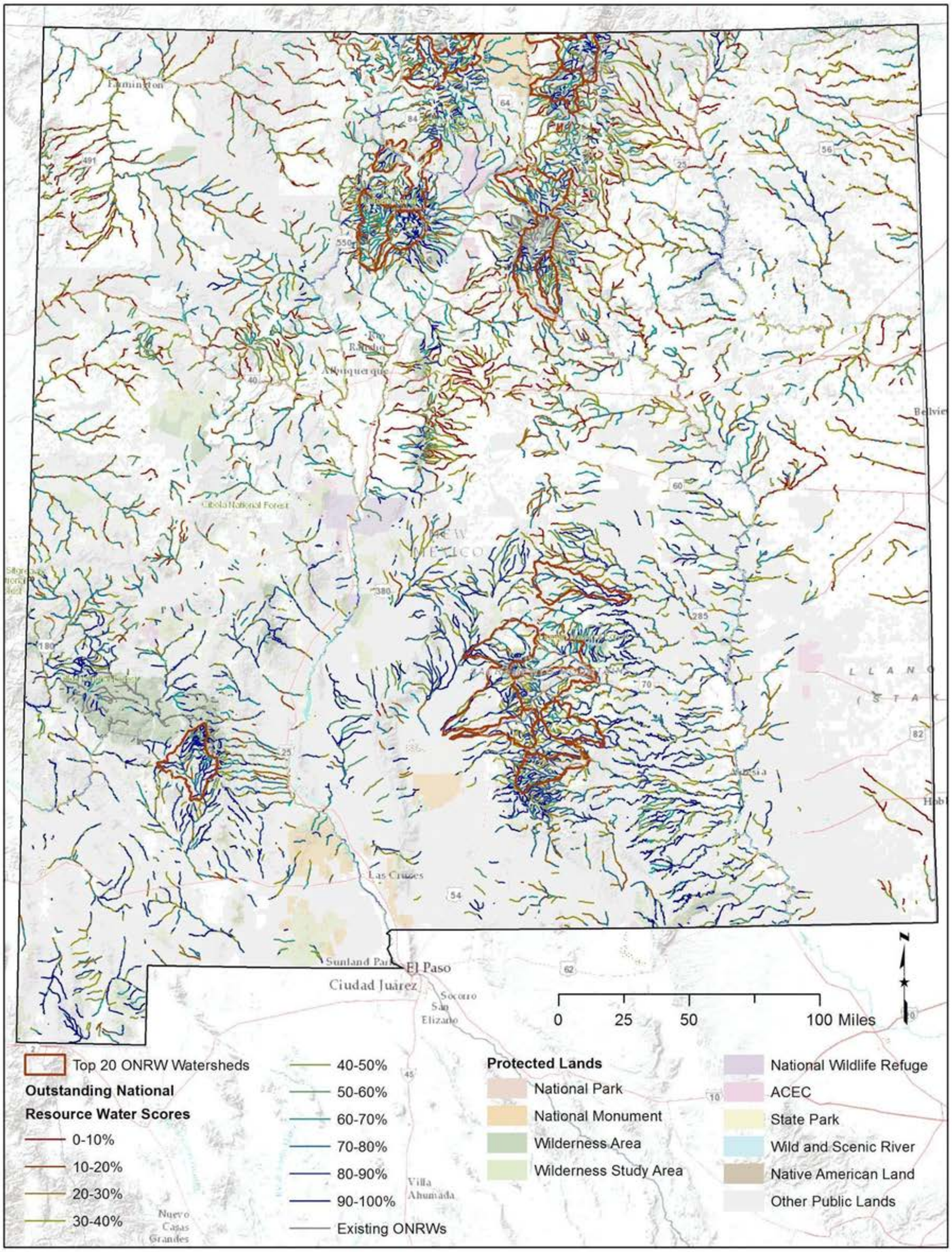
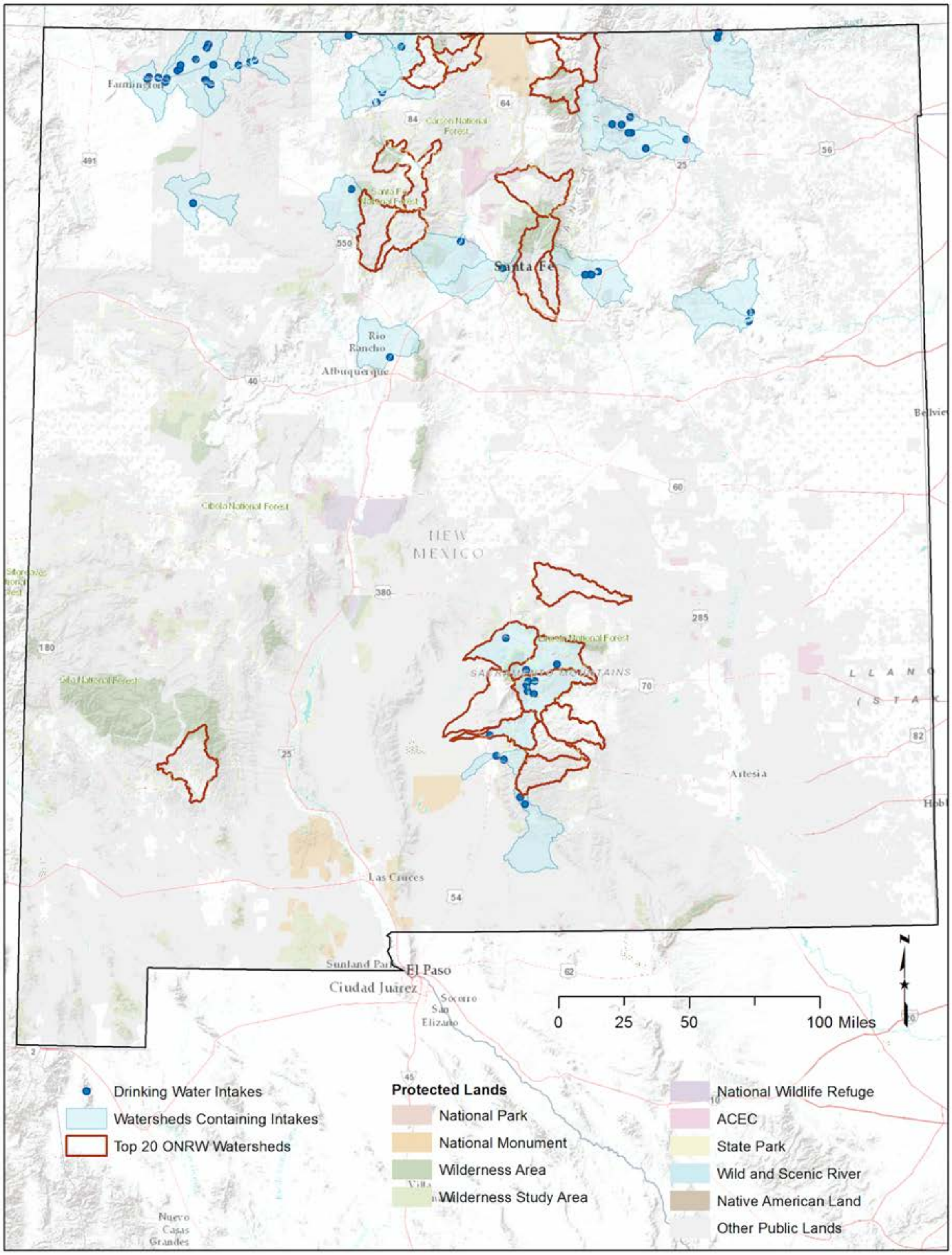
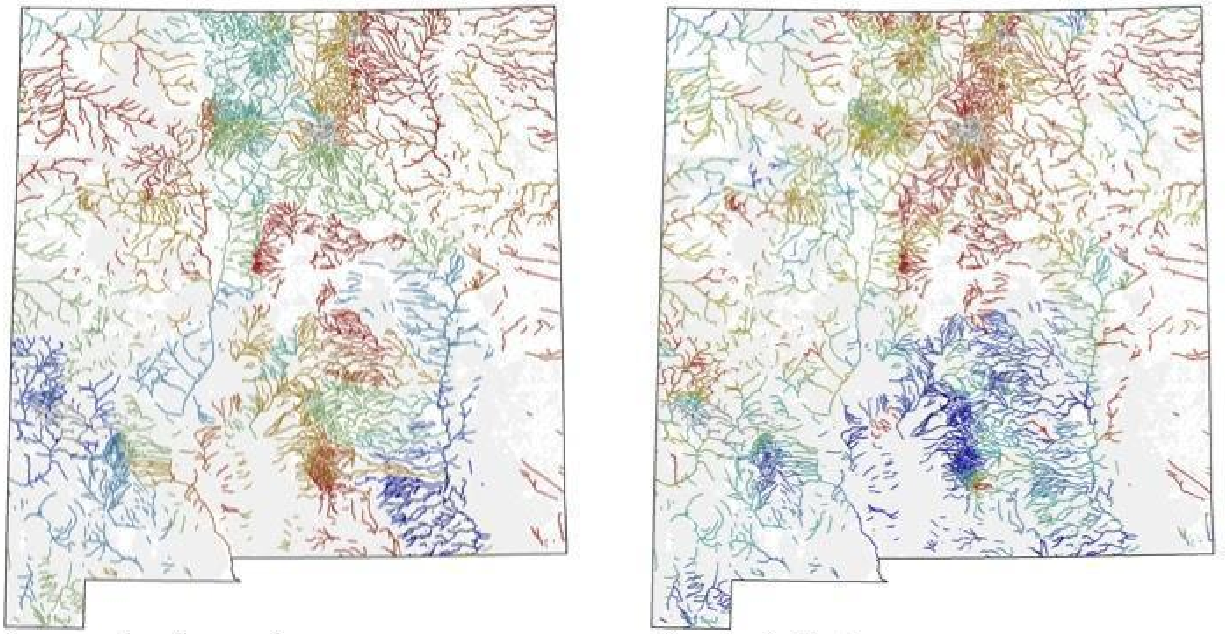
Maps



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

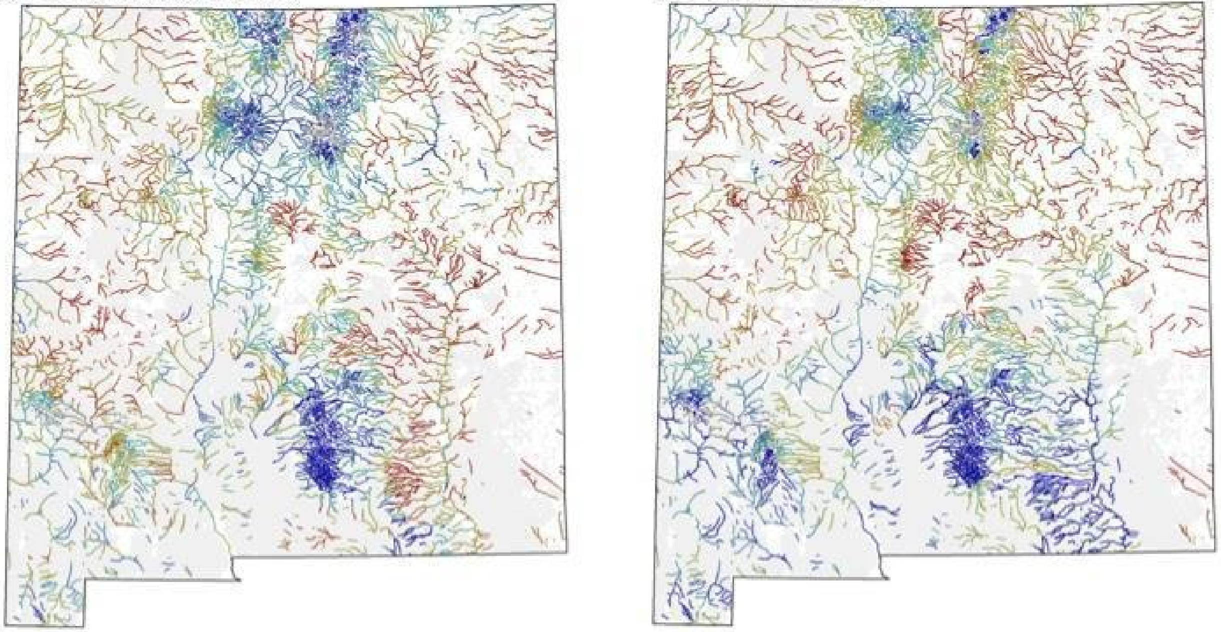


Map 2. Map of top 20 watersheds for ONRW (red) designation, overlaid on surface drinking water source watersheds.



a) at-risk species richness

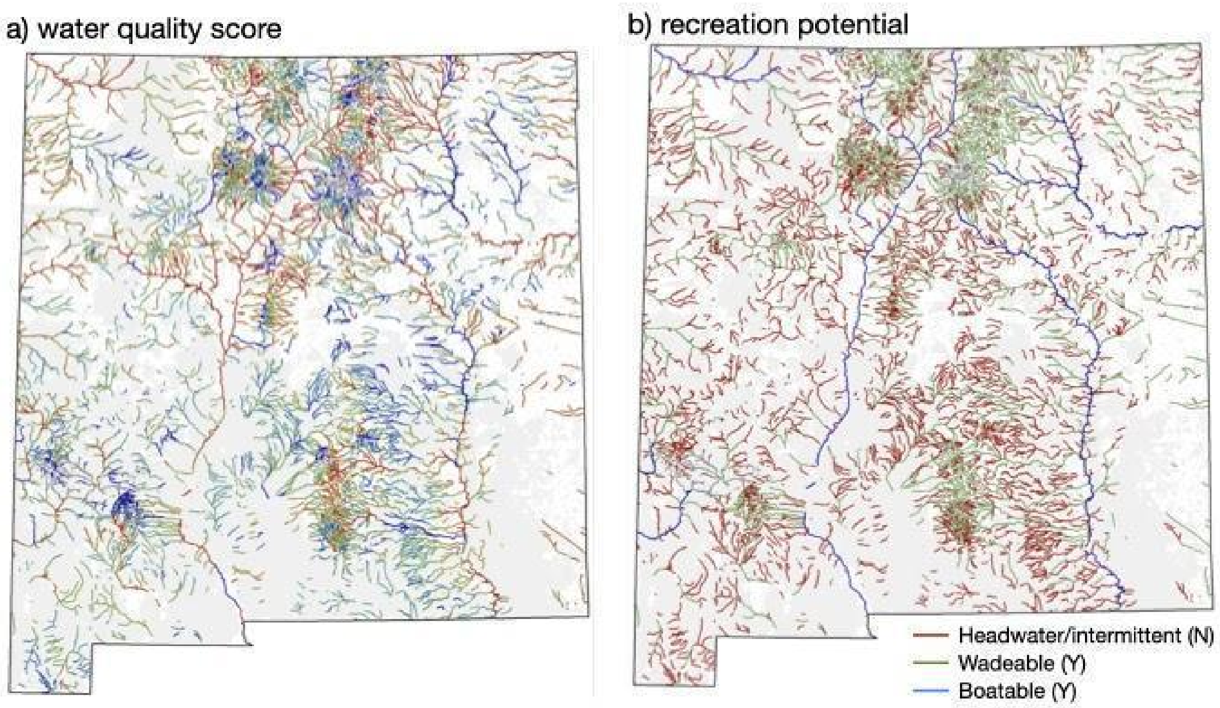
b) rarity-weighted species richness



c) ecosystem type rarity

d) ecological value

Map 3. 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 New Mexico. 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 4. Maps of a) water quality score (calculated as the fuzzy sum of water quality category, GAP protected status, and total degree of modification) and b) potential recreational value across New Mexico. In map (a), 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.

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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) criteria across New Mexico.

At-risk aquatic species richness. The at-risk aquatic species richness score represents the number of aquatic New Mexico Species of Greatest Conservation Need (SGCN) 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 New Mexico). 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).

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 New Mexico). 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 New Mexico Environment Department (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 = available data indicate that at least one designated or existing use is not supported but that 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. Impaired water bodies were excluded from analysis. Otherwise, these ordinal values (1-4) were rescaled 0-1 as described in Table 2 for integration into ONRW and SSW 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 New Mexico).

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.

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 (NM_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.

   $$\text{EcoScorePerc} = 1 - [(1 - \text{SGCNRichPerc}) * (1 - \text{RWRichPerc}) * (1 - \text{EcoRarPerc})]$$

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 (3).

   ONRWSegMean = EcoScorePerc + WQScorePerc + RecScore

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).

Generating reported summary statistics

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.

Literature Cited

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