Conservation Science Partners

Description of the approach, data, and analytical methods used to evaluate river systems in the western U.S.

December 4, 2017

Prepared for:

The Center for American Progress

By:

Dylan Harrison-Atlas, PhD
David M. Theobald, PhD
Brett G. Dickson, PhD
Vincent Landau, BSc
Ian Leinwand, MSc

Recommended citation: Harrison-Atlas, D., D. M. Theobald, B. G. Dickson, V. Landau, and I. Leinwand. 2017. Description of the approach, data, and analytical methods used to evaluate river systems in the western U.S. Conservation Science Partners, Truckee, CA.

Author contact: Brett G. Dickson (brett@csp-inc.org)

Impetus

Throughout history, rivers have been hotspots for human activity. In the western United States, widespread development has transformed much of the landscape, altering rivers and their ability to sustain services essential to both the region's ecology and economy. Rivers continue to face a variety of stressors, and so we believe there is an urgent need to evaluate and document the status of rivers across the American West. This assessment will enrich dialogue around the opportunities for river conservation and restoration by providing a consistent and reliable accounting of the current status of stressors to flowing waters in the region. The need to obtain reliable information on rivers is coupled with the obligation to communicate this information effectively. Given the broad reach of rivers across ownerships and livelihoods, there is tremendous value in supporting informed discussion among broad audiences and decision-makers alike.

Disappearing Rivers is the culmination of an analysis by Conservation Science Partners, in association with the Center for American Progress, to investigate how human development has altered rivers in the eleven western states. With this document we aim to describe the approach, datasets and analyses used to quantify the modification or alteration of rivers in the West. Maps, charts and major findings of the results of this work can be visualized through the *Disappearing Rivers* website and interactive web application.

Approach

Our approach and associated geospatial analyses were designed to assess rivers and streams over a broad geographic extent. The approach was developed to be complementary to other assessments that involve intensive (i.e., localized) sampling efforts to obtain data from observations in the field (e.g., US EPA Wadeable Streams Assessment). In comparison to field studies, a distinct advantage of a spatially extensive, comprehensive geospatial analysis is the ability to incorporate readily-available, extant data from a variety of sources. This enables the researcher to conduct broad-scale inquiries that would otherwise be cost prohibitive and pose significant logistical challenges. A spatially-explicit analysis is particularly valuable for uncovering and communicating meaningful linkages between human and river systems that might differ across scales and geographies. We used publically available datasets on rivers, streamflow, dams and other built features to create a consistent coverage across the 11-state study area (see Table 1). Although many of these datasets have evolved over time, we prioritized use of the most contemporary versions in our analyses.

Our overarching objective in modeling and mapping Disappearing Rivers was to quantify the degree to which rivers in the western US have been altered as a result of human activities. To disentangle the drivers of alteration, we separated this objective into two primary components: *flow alteration* and *floodplain alteration*. For each component, we detail the data sources and methods below. Separately, Appendix A details our approach to estimating the contribution of rivers to the outdoor recreation economy.

Table 1. Primary features and datasets used in the Disappearing Rivers analyses.

Feature	Dataset	Description	Source
River flowlines	National Hydrography Dataset (NHD) Medium Resolution (1:100,000)	Dataset representing rivers and streams as polylines. Contains attributes, e.g., feature type.	https://nhd.usgs.gov/index.html
Suite of geospatial data integrated with the National Hydrography Dataset	NHDPlus Version 2 (1:100,000)	Contains value added attributes such as flow estimates	http://www.horizon-systems.com/NHDPlus/index.php
Flow direction	HydroSHEDS (3 arc-seconds)	Gridded (raster) dataset representing drainage directions	https://hydrosheds.cr.usgs.gov/
Whitewater put-in locations	National Whitewater Inventory	Inventory of known put-in locations for whitewater recreation	https://www.americanwhitewater.org/
Dams	National Inventory of Dams (2016)	Comprehensive dataset of major dams maintained by the US Army Corps of Engineers	US Army Corps of Engineers (obtained through ProPublica.org)
Human modification	Human Modification (90-m resolution)	Composite index of human activity and associated land alteration; used to estimate natural area loss for the Disappearing West	https://databasin.org/galleries/7b9681f713fc478d81a7696d7ca77fc9
Protected areas	Protected Areas Database v1.4	Spatially-explicit inventory of areas designated with various levels of protection	https://gapanalysis.usgs.gov/padus/
Wild and Scenic Rivers	Wild and Scenic Rivers flowlines (1:24,000)	Rivers designated for protection by Congress under Wild & Scenic Act	https://www.rivers.gov/mapping-gis.php
Irrigated lands	MIrAD 250 (250 m)	MODIS-derived dataset depicting irrigated agricultural lands in 2012	https://earlywarning.usgs.gov/USirrigation
Abandoned coal mines	Abandoned Mine Land Inventory System	Location of coal mines not currently in operations and considered eligible for reclamation under the Abandoned Mine Reclamation Fund	https://amlis.osmre.gov/Default.aspx
Active coal mines	Coal Mine Production	Location of active coal mines	https://www.eia.gov/coal/data.php
Hard rock mines	Mineral Resources Data System (MRDS)	Location of hard rock mines (MRDS through 2011; excludes gravel)	https://mrdata.usgs.gov/mrds/

Methods

Mapping and analyzing river and stream features

A great diversity of rivers and streams occur in the West. For the purposes of this analysis, we focused on perennial rivers and streams having continuous flow throughout the year. These criteria were implemented by subsetting 'flowlines' from the National Hydrography Dataset (NHD Medium Resolution; USGS 2016) based on readily available attributes. Specifically, we selected 'River/Stream' features (coded: 46000), perennial streams (46006), and digitized centerlines for large rivers (55800). See NHD Feature Directory for more information. These features were also subset to include only those flowlines with mean annual flow > 1 cubic feet per second (cfs). We differentiated between river or stream segments[1] intended solely for mapping purposes from those that represented meaningful water bodies (e.g., lakes, reservoirs). In other words, those segments serving exclusively as cartographic features were excluded from analysis and did not contribute to our findings. Where appropriate, NHD high resolution (1:24,000) 'waterbodies' representing lakes and reservoirs were used to erase overlapping stream features from the final map result.

We grouped rivers into distinct, mutually exclusive bins based on their size. Specifically, we derived a classification system based on mean annual flow - the average flow occurring in a river segment over a yearly timeframe. Estimates of mean annual flow were obtained from NHDPlus Version 2 (USEPA 2016) and were used to subset rivers into three size classes: 1) small (< 6 cfs mean annual flow) which we generally call 'headwater streams'; 2) medium (6 to 163 cfs) which we found to coincide with 'wadeable rivers' and streams; and 3) large (> 163 cfs) which we determined to be consistent with 'boatable rivers.' We assembled a west-wide database of river put-in locations obtained from American Whitewater (2017) and used this database to inform our differentiation between rivers whose flows are generally consistent and supportive of wadeable versus boatable recreational activities. Minimum flows for boatable rivers were identified by examining the distribution of mean annual flows among put-in locations and selecting the median value. In total, we analyzed 145,855 miles of wadeable streams using our somewhat conservative threshold for differentiating boatable rivers. As a reference, the US Environmental Protection Agency (2006) considered 152,425 total miles of wadeable streams in the West. Flow-based thresholds for river size classifications are shown in Table 2.

[1] The NHD program defines a segment as a section of a flowline stretching from confluence to confluence, where a confluence is defined by the location where two or more rivers or streams meet, or a place where their characteristics otherwise change (e.g., a stream entering a lake). https://nhd.usgs.gov/Frequently+Asked+Questions+about+the+NHD+&+WBD.pdf

Table 2. Classification of river size by mean annual flow (cubic feet per second; cfs), estimated using the Enhanced Unit Runoff Method method from USGS NHDPlus Version 2.

River/stream size category	Flow thresholds (cfs)
All rivers and streams	> 1
Headwater streams	1 - 6
Wadeable rivers and streams	6 - 163
Boatable rivers	> 163

Estimating flow modification and alteration

The appropriation of water through dams, canals, and other engineering efforts has always fueled development in the West. As a result, many rivers no longer exist in their free-flowing and dynamic form (Graf 1999). We investigated the pervasiveness of these changes, analyzing the most recent data on rivers and dams to quantify the degree of flow alteration (termed 'flow restriction' for Disappearing Rivers).

The National Inventory of Dams (NID) data, developed and maintained by the US Army Corps of Engineers (USACE 2016), contains records of more than 90,000 major dams in the United States. We obtained the most current version of the NID data through a formal agreement with ProPublica. We assessed flow alteration on western rivers using the following analytical procedures, building on previous methods (Nilsson et al. 2005; Theobald et al. 2010). First, data were formatted to support the analysis. For example, we revised estimates of storage capacity to address cases where multiple dams were attributed full storage capacity for a shared reservoir (i.e., to prevent double counting of dam storage). In addition, we addressed gaps in coverage of the 'year built' attribute using a geostatistical modeling procedure to produce estimates based on construction activity from spatially adjacent dams. Normal storage, defined by the US Army Corps of Engineers as "total storage space in a reservoir below the normal retention level, including dead and inactive storage and excluding any flood control or surcharge storage" was used as the primary storage variable in this analysis.

NID point locations were converted to a raster dataset representing normal storage capacity. We assessed cumulative dam storage for each river pixel by performing a flow accumulation analysis of the dam storage raster in ArcGIS (v10.3; ESRI, Redlands, CA, USA). Cumulative dam storage represents the total volume of water stored by upstream dams within a river system. The directionality of flow between adjacent grid cells was assigned with a flow direction raster from HydroSheds (USGS) rather than from NHDPlus, because the flow direction raster accommodated the modeling of flow across watershed (i.e., hydrologic unit code 4, or 'HUC4') boundaries. Attribution of stream segments with cumulative dam storage values was performed with the zonal statistics algorithm in ArcGIS using catchment vector geographies as zones.

We built on methods that defined flow modification (F_m; Dynesius and Nilsson 1994; Nilsson et al. 2005; Theobald et al. 2010) as the fraction of an average year's discharge (virgin mean annual discharge, Q) divided by the accumulated storage capacity of reservoirs (S), as a percentage:

$$F_m = (Q / S) * 100$$

Flow modification values range between 0 for natural rivers (i.e., no dam regulation) and can exceed 1 in cases where dam storage capacity exceeds average annual flow. For example, values of $F_m > 1$ may occur in arid basins with high inter-annual variation in runoff. Additional numerical challenges with flow modification include the mathematical difficulty of division by zero for cases where there is no upstream storage.

To avoid the mathematical challenges associated with F_m, we developed an alternative we call *flow alteration*, which is the inverse of the degree of river 'naturalness,' where:

$$F_r = 1 - (Q/(Q + S)).$$

Values of F_r range from 0 for natural, fully unregulated rivers (no dams or reservoirs above a given segment) and may approach 1 in highly regulated contexts. Advantages of this formulation include that it measures a departure from 'natural,' is normalized from 0 to 1 so that it can be combined with other metrics, is more sensitive to lower degrees of modification, and can reasonably accommodate instances of extremely high modification (i.e., outliers) through smoothing. For these reasons, we elected to use flow alteration as the primary metric to quantify flow modification in the Disappearing Rivers analysis. Flow alteration generally increases downstream from dams but may be offset by inputs from unregulated tributaries.

We computed flow for all stream and river segments using mean annual flow as the discharge component. Estimates of mean annual flow were produced using the Enhanced Unit Runoff Method (EROM) and were obtained from the NHDPlus Version 2 dataset. Flow estimates are representative of the 1971-2000 time period and were calibrated against stream gauge data. For more information on data and methods for streamflow estimation, see McKay et al. (2012).

Quantifying floodplain alteration

Human activities occurring in areas adjacent to rivers and streams have profound effects on freshwater systems. We define a floodplain as the land area adjacent to a river (or stream) bank and between valley bottom edges, composed of unconsolidated sedimentary deposits and subject to periodic flooding. Note that this definition of floodplain is distinct from one based on statistical flood recurrence intervals and commonly used in legal domains. We generated a novel dataset using a method that estimates the location and extent of valley bottoms (including floodplains) at a 10-meter resolution using USGS National Elevation Data and an algorithm that accounts for stream power, local stream gradient, and adjacent valley topography (Salo et al. 2016). We implemented the algorithm in the Google Earth Engine environment and supplemented the valley bottom delineation by 'burning in' headwater streams from NHD High Resolution (1:24,000) flowlines. We used a 'human modification' layer (Theobald 2013;

Theobald et al. 2016) to estimate the extent and intensity of human activities occurring within valley bottom floodplains, circa 2011. Human modification is a composite index of human activity describing the degree to which lands have been converted from natural conditions. It has previously been used to quantify natural land area loss for the western United States (see Disappearing West website). Human modification is spatially-explicit and exists as a continuous coverage for the western United States at a 30-meter resolution. We spatially linked valley bottom geographies with individual flowline segments using catchments defined by NHDPlus Version 2. Catchments delineate land areas that contribute runoff directly to adjacent streams. To estimate the degree of floodplain alteration corresponding to each flowline, we set our analysis mask to include only human modification pixels within areas delineated as valley bottom and then computed the mean degree of human modification value for each catchment. These results for the degree of floodplain alteration were joined to the flowlines dataset using a unique identifier provided by NHDPlus Version 2. We note that this metric is also surrogate for some aspects of water quantity and quality that might extend beyond the valley bottom, as some of the water infrastructure is captured through land cover classes used in the human modification dataset. Also, although we call this area along rivers within the valley bottom the “floodplain”, we did not attempt to delineate floodplains associated with any particular precipitation amount (e.g. 100-year floodplain) and so should not be construed as having some regulatory application.

Thresholding flow alteration and floodplain alteration

Both flow alteration and floodplain alteration were computed as continuous variables. While a continuous representation was necessary to capture variation that exists across the West, additional steps were needed to assess the degree to which river systems have been altered from their natural conditions. For each of these two key variables, we estimated reference values that were representative of the best attainable conditions within the region. Reference conditions are often used as a baseline to assess how current conditions may deviate from a former often less developed state (Stoddard et al. 2006).

We used the Protected Areas Database (PAD-US v1.4, USGS 2016) to identify areas protected with GAP status 1 and 2 as those lands most likely to represent least altered conditions in the western U.S. that could be used as a reference state. Among these catchments, we used the average degree of human modification as a threshold for differentiating the continuous floodplain alteration variable (FA) into a binary classification as shown below:

Floodplain unaltered: FA <= FA’
Floodplain altered: FA > FA’

where VA’ is the average degree of human modification among catchments located in protected areas (GAP status 1 and 2).

We used a similar process to convert flow alteration from a continuous variable into a binary classification suitable for impact assessment. Rather than rely on land protection as a surrogate for river protection, we used designations provided under the National Wild and Scenic Rivers Act of 1968. We focused specifically on river segments designated as “wild” or “scenic” as opposed to “recreational” as our aim was to assess how flow alteration varies among minimally altered rivers. Thus, we computed the average flow alteration value for wild and scenic rivers and used that to inform the classification of flow-impacted segments:

$$\text{Flow unaltered: } F_u \leq F_r'$$
$$\text{Flow altered: } F_a > F_r'$$

where F_r' = average flow alteration value among rivers designated as “wild” or “scenic” under the National Wild and Scenic Rivers Act.

Combined impacts of flow alteration and floodplain alteration

Cumulative impacts may arise from multiple sources of alteration. We produced an integrative measure to account for the combined influence (i.e., impact) of flow alteration and floodplain alteration to quantitative stressors that influence river condition. We used an ‘increasive’ function known as “fuzzy sum” (Bonham-Carter 1994; Theobald 2013) to estimate impacts using the combined evidence from flow alteration and floodplain alteration at the segment level. The increasive function is specified for flow alteration (FR) and floodplain alteration (FA):

$$\text{Combined impacts} = 1 - ((1- F_r') * (1- FA')).$$

Values range between 0 and 1, with higher values indicative of greater impact (weight of evidence). We refer to this derived, combined value as the degree of alteration.

Quantification of river and stream modification

We used the thresholded variables for floodplain alteration and flow alteration as the basis for quantifying river (or stream) modification across the West. A river segment could be modified in terms of: a) floodplain alteration; b) flow alteration; or c) either floodplain alteration or flow alteration. For each of these three categories, we analyzed the extent of modification using the ratio of affected river length to total river length. Because the primary goal of this analysis was to provide reliable information in ways that resonate with decision makers, we summarized findings both by multiple watershed units as well as to illuminate patterns occurring at levels defined by west-wide, state, county, and congressional district geographies. For the purposes of the interactive web application, we present all river or stream segment modification and total modification values as percentages. For those streams or rivers passing through multiple states, we calculated the total percent modification at the state level, based only on those segments within a given state. The total percent modified for the Colorado River (54%) was calculated according to its full length, from headwaters to terminus at the US-Mexico border.

In addition, we analyzed how the degree of river modification (i.e. ‘alteration’) differed between protected and unprotected areas of the western US, within and across ownerships. These methods and results are detailed in Appendix B.

Fragmentation by dams and effects of diversions

For all rivers (or streams) in the West, we calculated the fragmentation of all river networks caused by dams using a distance-weighted average calculation. That is, we calculated mean distance of streams from river mouth to headwater along the river network for the 'natural' (w/out dams) and compared that to the mean distance along the river network including breaks in rivers caused by dams. To account for the uneven distribution of river/stream lengths (i.e., there are few relatively long, contiguous river networks such as the Colorado River, and many smaller, discontinuous river networks, characteristic especially in more arid parts of the West, such as Nevada), we calculated a length-weighted average. Specifically, we squared the length of each continuous river network, summed these squared lengths, calculated the mean, and then calculated the square-root of the squared-summed-mean length. We made the assumption that all dams are equal in their fragmenting effects and that they fragment rivers and streams completely (though there may be some that have, for example, fish ladders and other adaptations to try to reduce fragmentation and disruption of fish passage we did not have data to distinguish these). Some large canals are fed by reservoir water behind dams and therefore included as fragmenting features. Therefore, we calculated, in addition to the dam fragmentation metric, a second metric to estimate the fragmenting effects of 'major' diversions (supply and irrigation ditches as well as trans-basin diversions) as well as dams, which we mapped by extracting these features from the standardized USGS NHD High resolution dataset. Finally, we also considered the effects of culverts and bridges at the intersection of roads and rivers/streams as a third measure of river fragmentation. Although these features in general do not restrict flow like a reservoir or extract water like a diversion, they can have serious consequences for water quality and quantity, and especially on fish passage. We also do not include naturally occurring features such as waterfalls as fragmenting features in our calculations.

Vetting process

We implemented a three-step vetting process to assess our results for flow alteration and floodplain alteration. First, we compared our findings against independent data sources and utilized expert opinion to evaluate the reliability of our results. Because many of the data summaries we produced were novel and had no direct comparison with published sources, we focused largely on overall trends and patterns as opposed to specific estimates. Second, we performed a thorough review of the data to check for internal consistency among our results. This step also ensured that statistical summaries generated for geographic subsets were in alignment with each other. Lastly, we conducted a thorough visual inspection of the flowlines data to identify river segments attributed with anomalous values and in need of correction. Visual inspections allowed us to evaluate flowlines data within their geospatial context and were particularly valuable for assessing flow alteration in relation to dam locations along river networks. Problematic segments identified through visual inspection were flagged and revised based on values of neighboring, upstream segments during subsequent editing sessions. Manual edits were made for display purposes only and were enforced on approximately 1% of flowlines.

Stressors

In addition to flow alteration and floodplain alteration, rivers are often subjected to a diverse array of stressors. We included mining and irrigated agricultural land as two additional stressors associated with the development of the American West, and with important ties to river systems (Mattson and Angermeier 2007). For each of these stressors, we identified relevant datasets and mapped their distribution across the West. Irrigation of agricultural lands is the largest sector of water use. We acquired geospatial data on irrigated lands from the USGS (2015). Irrigated lands were classified at a 250-m resolution using 2012 MODIS satellite data (see Pervez and Brown 2010 for detailed methods). Data on coal and hardrock mining activities were obtained from multiple sources (Table 1). Abandoned mines records were extracted from the AMLIS database produced by the Office of Surface Mining Reclamation and Enforcement (2016). The locations of active coal mines were obtained from the US Energy Information Administration through the coal data browser.

We examined local and regional patterns for both irrigation and mining activities, providing data summaries for multiple geographies. Within geographic units of interest (e.g., state and HUC8 scales) we assessed the distribution of these activities across the landscape. We computed the total area occupied by irrigation. For coal and hardrock mines, we quantified the number of distinct mines occurring locally as well as cumulatively to account for mines located within an upstream portion of a watershed.

Key Results and Discussion

Across the West, rivers have experienced extensive modification with nearly half of all river miles modified by flow alteration or floodplain alteration (Table 3). We found clear trends in the extent of flow alteration and floodplain alteration among river classes with headwaters tending to be the least modified, followed by wadeable streams and boatable rivers. As a group, boatable rivers have been the most widely altered with modification occurring on greater than 82% of river miles. In contrast, headwaters were consistently the least modified river class with approximately 36% of rivers modified by length. We found that floodplain alteration exerts a larger footprint than flow alteration and that this pattern is consistent across river size classes.

Table 3. Percent modification (by length) of rivers and streams in the 11 western states by flow alteration, floodplain alteration, and the combined effects of the two.

River class	Due to flow alteration	Due to floodplain alteration	Due to flow alteration *or* floodplain alteration
All rivers	*20.8%*	*42.0%*	*49.0%*
Headwaters	8.7%	32.6%	35.9%
Wadeable streams	17.9%	42.6%	48.4%
Boatable rivers	60.6%	62.8%	82.4%

We found considerable variation in the extent of modification occurring at a state level. For example, we estimated that flow alteration and floodplain alteration have combined to alter nearly 70% of river miles in Utah (Table 4). By comparison, we found that one third (33%) of river miles have been affected in Idaho. Greater than 90% of boatable rivers in Utah, Nevada and Arizona have been affected by flow alteration (Table 5). In contrast, we found that flow alteration is less extensive in the Pacific Northwest with estimates approaching 30% in Washington state and 40.4% in Oregon. At a state level, floodplain alteration is most extensive in Colorado (54.3%), followed by Utah (52.8%) and New Mexico (48.7%; Table 6). Modification of headwater floodplains is most widespread in Colorado (54.3%) and is least pervasive in Idaho (28.9%).

Table 4. Percent modification (by length) of rivers and streams in the 11 western states due to combined effects of flow alteration and floodplain alteration.

State	All rivers	Headwaters	Wadeable streams	Boatable rivers
Arizona	62.7%	31.6%	56.4%	95.6%
California	44.5%	35.8%	40.5%	79.6%
Colorado	63.0%	50.6%	61.1%	97.1%
Idaho	33.0%	22.2%	36.9%	69.2%
Montana	49.9%	32.2%	51.4%	86.6%
New Mexico	63.2%	45.8%	55.7%	94.1%
Nevada	52.9%	36.2%	64.0%	96.2%
Oregon	52.0%	43.2%	49.6%	79.3%
Utah	69.6%	50.6%	73.5%	99.7%
Washington	46.0%	41.9%	42.1%	68.4%
Wyoming	48.9%	33.3%	49.3%	85.3%

Table 5. Percent modification (by length) of rivers and streams in the 11 western states due to flow alteration.

State	All rivers	Headwaters	Wadeable streams	Boatable rivers
Arizona	47.7%	10.9%	36.6%	92.2%
California	18.4%	7.8%	13.1%	63.5%
Colorado	32.1%	15.6%	27.4%	86.5%
Idaho	11.1%	3.7%	10.1%	48.6%
Montana	24.4%	9.0%	23.2%	64.1%
New Mexico	35.5%	19.1%	20.7%	86.1%
Nevada	27.4%	10.1%	31.3%	93.9%
Oregon	14.6%	8.4%	10.9%	40.4%
Utah	40.3%	12.7%	40.7%	96.0%
Washington	10.0%	6.6%	6.4%	29.9%
Wyoming	30.2%	15.0%	28.9%	72.9%

Table 6. Percent modification (by length) of rivers and streams in the 11 western states due to floodplain alteration.

State	All rivers	Headwaters	Wadeable streams	Boatable rivers
Arizona	32.8%	25.6%	34.3%	35.5%
California	38.3%	33.3%	36.0%	59.2%
Colorado	54.3%	45.4%	53.5%	76.5%
Idaho	28.9%	20.7%	33.3%	51.5%
Montana	43.0%	29.0%	44.4%	70.6%
New Mexico	48.7%	35.9%	49.3%	54.6%
Nevada	42.8%	30.9%	50.8%	73.4%
Oregon	47.3%	40.1%	46.1%	67.3%
Utah	52.8%	44.2%	59.2%	56.2%
Washington	43.8%	40.6%	41.2%	59.6%
Wyoming	38.4%	25.8%	38.5%	68.2%

In terms of river/stream fragmentation -- assuming that dams impair or otherwise 'sever' pathways for movement of fish and other aquatic species -- we found that, without dams (i.e., "natural rivers"), the length-weighted average of rivers west-wide would be 1980.9 miles, whereas the length-weighted average of stream segments between dams (i.e. fragmented river) was only 311.2 miles. This suggests that, dams have highly fragmented our natural river and stream networks and reduced their average length by approximately four-fifths (84%). When we calculated the additional effects of major diversions the average length of river/stream segments decreased to 169.5 miles (about 8.6% of natural, a reduction of 91.4%). Finally, when we included the nearly 1 million road/stream crossings, the average length declined to 8.3 miles (about 0.4% of natural). That is, a fish can only swim less than one-half of one percent of what was historically possible before hitting a dam, diversion or culvert. We again emphasize that these metrics calculate the effects of human features on rivers in a spatially-explicit manner -- accounting for the location of the features within the river network, though inclusion of diversions and especially the effects of culverts and bridges on river ecosystems is less certain.

National and regional context

Disappearing Rivers is an effort to capture the current state of western rivers using the best available datasets and advancements in geospatial technology. Our approach differs in notable ways from field-based sampling efforts and complements previous assessments through integration of key datasets using a consistent geospatial framework. A major difference is that our analysis focuses on quantifying the drivers of river alteration as opposed to documenting changes in the biological, chemical or physical condition that may result from such drivers. In particular, two assessments by the United States Environmental Protection Agency are instructive for informing discussion around Disappearing Rivers and for placing findings from this analysis within a broader context. Below, we highlight topline numbers from these EPA studies. We refer the interested reader to explore these studies in more detail online and by reviewing published reports (USEPA 2006; USEPA 2016).

Key findings from EPA *National Rivers and Streams Assessment* (sampling from 2008-2009; USEPA 2016) for wadeable streams AND large rivers in the western United States:

- 53.0% of river/stream miles have moderate to high levels of stressors;
- 71.0% of rivers/streams (by length) experience riparian disturbance at levels that are considered medium to high.

Key findings from EPA *Wadeable Streams Assessment* (sampling from 2000-2004; USEPA 2006) for wadeable rivers in the western United States:

- 53.2% of stream miles have moderate to high levels of stressors, which indicate fair to poor condition;
- 65.2% of streams experience riparian (i.e. streamside vegetation) disturbance at levels that are considered medium to high.

Appropriate uses of the data products

We intend for these data to be used to inform discussion around western rivers, including identifying the patterns and locations of rivers and streams that have likely been altered by human activity. Our analyses were informed using data produced at 1:24-100,000 scale and reflect our interest in drawing meaningful inference through the use of high resolution data across broad geographic extent. Because we used varying resolutions for the input datasets, we anticipate that Disappearing Rivers data products are most relevant for watershed-scale analysis (e.g. 12-digit HUC unit and coarser). In addition, we recognize the potential value of these data products for reach-level assessment and caution prospective users to consider any scale-dependent limitations in the data that may affect their investigation.

Any applications or publications drawing on these data, in novel analyses, reports, peer-reviewed articles, theses, or other forms, should be undertaken in consultation with CSP. The source of the data should be properly referenced using the citation provided on the cover page.

Caveats and limitations

Our focus on flow alteration and floodplain alteration highlights two of the key drivers that have contributed to the ubiquitous transformation of modern day river systems. It was critical that we capture these drivers by leveraging consistent, readily available, and high quality spatial data for the 11 western states. There is an extensive body of literature, particularly around flow regimes and the ways in which dams and other aspects of the built environment have altered streamflow dynamics. For more information on flow regulation and its significance to river systems, we refer the reader to Poff et al. (1997), Bunn and Arthington (2002), Richter et al. (2003), and Nilsson et al. (2005). Background information on rivers (Vannote et al. 1980; Poff et al. 1997), their floodplains, and interactions with floodplains (Junk et al. 1989) also provides valuable context.

It is worth noting that assumptions are an inherent part of every modeling exercise. A key assumption we made in this analysis was to set thresholds for the classification of river segments based on flow alteration and floodplain alteration. In moving from a continuous to a binary representation, we converted segments into classes to permit a simple and transparent metric of overall river alteration. Although our thresholds were informed using appropriate methods and reliable data, we note that rivers exhibit tremendous diversity across the West, in terms of the physical and ecological attributes that influence their function and resilience. Furthermore, we used thresholds based on annual average discharge, and so made a simplifying assumption about the variability of seasonal flows. The practical significance of this is that rivers are likely to express differential susceptibilities to stressors including flow alteration and floodplain alteration. That is, for a given magnitude of flow alteration, for example, ecological responses may vary across river systems and geographies. Capturing these differences was beyond the scope of this analysis but would help to reveal which rivers or groups of rivers are most sensitive to these and other forms of human modification. Finally, while we quantified the degree of stress of western rivers, which can be a strong indicator of ecological condition (e.g., Stoddard et al. 2006), we did not measure biological condition, per se.

Acknowledgments

We thank ProPublica for providing the 2016 NID spatial data. We thank D. Merritt for constructive comments on an earlier version of this document and J. Gage for technical support. We also thank the many federal, state, and NGO partners who provided data or advice that was integral to our results.

Literature Cited

American Whitewater. 2017. National River Database. Accessed at: https://www.americanwhitewater.org/content/River/view/.

Bonham-Carter G. 1994. Geographic information systems for geoscientists. Elsevier, 398 pgs.

Bunn, S. and Arthington, A. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30: 492–507.

Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753-762

Graf, W. 1999. Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research* 35: 1305-1311.

Junk, W., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pages 110-127 *in* D.P. Dodge, ed. Proceedings of the International Large River Symposium (LARS). Canadian Special Publication of Fisheries and Aquatic Sciences 106.

McKay, L., T. Bondelid, T. Dewald, J. Johnston, R. Moore, and A. Rea. 2012. NHDPlus Version 2: User Guide.

Mattson, K. M., & Angermeier, P. L. 2007. Integrating human impacts and ecological integrity into a risk-based protocol for conservation planning. *Environmental management*, *39*(1), 125-138.

Nilsson, C., C.A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308: 405-408.

Office of Surface Mining Reclamation and Enforcement. 2016. Abandoned Mine Land Inventory System (e-AMLIS). Accessed at: https://amlis.osmre.gov/Default.aspx.

Pervez, M.S. and J.F. Brown. 2010. Mapping irrigated lands at 250-m scale by merging MODIS data and national agricultural statistics. *Remote Sensing* 2: 2388-2412.

Poff, N.L., D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. *Bioscience* 47: 769-784.

Richter, B.D., R. Mathews, D.L. Harrison, and R. Wigington. 2003. Ecologically sustainable water management: managing river flows for river integrity. *Ecological Applications* 13: 206–224.

Salo, J. A., D.M. Theobald, and T.C. Brown. 2016. Evaluation of methods for delineating riparian zones in a semi-arid montane watershed. *JAWRA Journal of the American Water Resources Association* 52: 632-647.

Stoddard J.L., D.P. Larsen, C.P. Hawkins, K.R. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16: 1267-1276.

Theobald, D.M., D.M. Merritt, and J.B. Norman, III. 2010. Assessment of Threats to Riparian Ecosystems in the Western U.S. A report presented to The Western Environmental Threats Assessment Center, Prineville, OR by The USDA Stream Systems Technology Center and Colorado State University, Fort Collins, CO, 61 pgs.

Theobald, D.M. 2013. A general model to quantify ecological integrity for landscape assessments and US application. *Landscape ecology* 28: 1859-1874.

Theobald, D.M., L.J. Zachmann, B.G. Dickson, M.E. Gray, C.M. Albano, V. Landau, and D. Harrison-Atlas. 2016. Description of the approach, data, and analytical methods used to estimate natural land loss in the western U.S. Conservation Science Partners, unpublished technical report. Available at: https://disappearingwest.org/methodology.pdf.

U.S. Army Corps of Engineers (USACE). 2016. National Inventory of Dams. Accessed at http://nid.usace.army.mil/cm_apex/f?p=838:12.

U.S. Environmental Protection Agency (EPA). 2006. Wadeable streams assessment: a collaborative survey of the nation’s streams (EPA 841/B-06/002). Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2016. National rivers and streams assessment 2008-2009: a collaborative survey (EPA/841/R-16/007). Office of Water and Office of Research and Development, Washington, D.C.

U.S. Geological Survey (USGS). 2015. Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Dataset for the United States (MIrAD-US). Accessed at: https://earlywarning.usgs.gov/USirrigation.

U.S. Geological Survey (USGS). 2016. The National Hydrography Dataset. Accessed at: https://nhd.usgs.gov/NHD_Medium_Resolution.html.

U.S. Geological Survey (USGS), Gap Analysis Program (GAP). 2016. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class.

Vannote, R. L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.

Appendix A. Estimating spending on the outdoor recreation economy and making comparisons among western watersheds.

Outdoor recreation is a major economic driver for western states (Outdoor Industry Association 2017) and an important component of tourism that helps sustain local communities. The Outdoor Recreation Economy (ORE) is supported by a diverse set of outdoor industries and recreational activities that occur across landscapes and ecological settings. An open question involves the contribution of rivers to outdoor recreation.

The objectives of this analysis were to assess the influence of rivers and related amenities to ORE with the ultimate aim of capturing ORE in terms of watershed geographies. In the absence of data that could be used to directly infer river-based economies, we used a modeling approach to produce watershed-based estimates using a consistent set of data and assumptions. Broadly, this analysis consisted of three steps: 1. acquisition and processing of county-based economic data; 2. translation of county-based estimates to watershed units; and 3. statistical modeling of ORE.

We obtained relevant economic information for outdoor recreation entries categorized by the 2017 North American Industry Classification System (NAICS). We selected code 713990 as the most relevant class for the purposes of this analysis because it includes establishments that primarily provide recreational and amusement services and is consistent with that used by the USDA Economic Research Service in its assessment of recreation counties. Relevant entries under this code include recreational white water rafting, kayaking, river rafting, outfitters (i.e., providing trips and equipment), fishing guide services, and fishing clubs. We acquired county-based estimates of recreation industry earnings for 2015 from the Bureau of Economic Analysis' Regional Local Area Personal Income and Employment database. Estimates at this NAICS level were not reported for about 30% of counties. Not surprisingly, these counties tended to be small in population. Missing values were modeled using K-nearest neighbors function where distance was measured in terms of county population. Some of the unreported values were classified as "L" meaning they were less than $25,000. For these cases estimates were capped at $25,000.

A common challenge in natural resource assessments occurs when data are aggregated by geographic units that are defined by political as opposed to ecological boundaries. For the purposes of this analysis, we determined that watershed units (Hydrologic Unit Code 8) were appropriate for our ORE analysis. Thus, we developed a novel approach to translate county-based estimates of economic output into watershed units. The Watershed Economic Translation (WET) algorithm apportions economic estimates obtained at the county level into overlapping watershed units based on the geographic extent of river and stream networks within a county. To account for the fact that large rivers are likely to be more influential than small streams in contributing to economic output, we used discharge-weighted stream length as a weighting factor when translating from county-based estimates into corresponding watershed units. WET outputs contain economic estimates relevant for watershed-based analysis and are produced in such a way as to conserve total economic value (i.e. no double counting where multiple watersheds occur within a county).

We used a statistical modeling approach to identify and characterize river-related influences of ORE. Using the watershed-based estimates from WET as the response variable, we developed a set of linear regression models using a suite of explanatory variables. Although the NAICS code used to estimate ORE was defined as precisely as possible to target (outdoor) recreation-related industries, its inclusion of other, amusement-oriented industries, necessitated an approach that could account for these "urban" drivers while allowing us to focus on other variables of interest (i.e., river-centric drivers). Our principal aim here was to model economic drivers in such a way as to reflect contributions of natural resources and river-based amenities. Thus, we considered two broadly-defined classes of explanatory variable, namely, urban influences and river resources and related amenities. A list of candidate explanatory variables is provided in Table 1.

Table 1. Candidate explanatory variables used to model the Outdoor Recreation Economy.

Variable	**Description**	**Data source**	**Included in final model**
NUM_WW	Number of whitewater put-in locations	American Whitewater	Yes
DEV_AREA	Urbanized land area (NLCD classes 21-24)	National Land Cover Dataset 2011 (NCLD; USGS)	Yes
POPULATION	Total population	NASA, SEDAC (http://sedac.ciesin.columbia.edu/data/collection/gpw-v4/sets/browse)	Yes
SEASONAL_HOMES	Number of homes whose use is primarily seasonal	U.S. Census Seasonal and Recreational Housing, American Community Survey	Yes
FAC_NEAR_H20	Number of recreation facilities on Forest Service land located adjacent to rivers	USFS	No
BOAT_MOD_LENGTH		Derived	No
AREAKM2	Watershed area in square kilometers	Derived	No
PROT_AREA	Protected land area (GAP status 1 or 2)	GAP	No
HOUSING_DENS	Mean housing density	U.S. Census	No

We assessed correlations among candidate variables, selecting from among highly correlated pairs of variables those with the strongest and clearest linkage to ORE. We elected to construct simple models on the basis of parsimony and removed variables that were found to be insignificant. Results for the final model are shown in Table 2. Performance metrics for the statistical model suggest that it provides a reasonable approximation for outdoor recreation (adjusted R-squared = 0.55; *p*-value: < 2.2e-16).

Table 2. Standardized coefficients for the final ORE model: sqrt(ORE_DLRS) ~ NUM_WW + DEV_AREA + POPULATION + SEASONAL_HOMES. All variables were statistically significant at *p* < 0.001.

Variable	Standardized coefficient (SE)
NUM_WW	0.22 (0.02)
DEV_AREA	0.28 (0.06)
POPULATION	0.37 (0.06)
SEASONAL_HOMES	0.15 (0.03)

Next, as a final step in our evaluation of western rivers and the benefits that flow from them, we assessed the contribution of rivers to the outdoor recreation economy (ORE; spending, in dollars). Our assessment, which builds on the aforementioned statistical modeling approach to estimate economic spending at the watershed (HUC8) level, provides a means to compare outdoor recreation economies as well as to investigate driving factors. Below we provide a series of comparisons to assess differences in outdoor recreation economies that exist among watersheds that vary in terms of river density.

We define river density as the ratio of river length to watershed area, and we weighted river densities to account for differences in size of rivers, associated with our three classes. River densities are shaped largely by climate and physical characteristics and thus vary across the western United States.

We performed comparisons of outdoor recreation economies for three subsets of watersheds based on the density of:

1. All rivers and streams;
2. Boatable rivers;
3. Unmodified rivers and streams.

To capture economic differences in watersheds that arise at various river densities, we considered multiple thresholds for defining low versus high density groups. For each river subset we classified watersheds into low and high density classes using three empirically defined breaks based on the distribution of river densities:

1. Low: 10th percentile and below, High: 90th percentile and above
2. Low: 20th percentile and below, High: 80th percentile and above
3. Low: 25th percentile and below, High: 75th percentile and above.

We found that differences in outdoor recreation economies were greatest among watersheds when considering the density of *all rivers and streams*, across the West and within states (Table 3 and 4). For example, across the West, *we found that watersheds with a higher density (90th percentile) of rivers have outdoor recreation economies that are ~717% greater on average than watersheds with a lower density (10th percentile) of rivers.* When considering differences among watersheds grouped into lower (25th percentile) and upper (75th percentile) quartiles based on river density, we found that watersheds with a higher density of rivers have outdoor recreation economies that are ~109% greater on average than watersheds with a lower river density.

Table 3. Comparison of Outdoor Recreation Economies (ORE) among watersheds and all rivers and streams in the western United States.

Percentiles	Average ORE for Low Density group	Average ORE for High Density group	Percent difference
10, 90	$2,174,310	$17,764,574	717.0%
20, 80	$5,628,438	$16,657,557	196.0%
25, 75	$8,026,282	$16,731,721	108.5%

Among watersheds containing boatable rivers, higher density groups also tended to have greater ORE values than their lower density counterparts (Table 5). These differences were greatest among the 10th and 90th percentile groups. Using this classification we found that watersheds with a higher density of rivers have outdoor recreation economies that are ~169% greater on average than watersheds with a lower density. These differences were less dramatic for classifications based on alternative density thresholds (i.e. those including 20th and 25th percentiles).

Table 4. Comparison of Outdoor Recreation Economies (ORE) among watersheds for all rivers and streams in the western United States, by state.

STATE	Average ORE for Low Density group (10th percentile)	Average ORE for High Density group (90th percentile)	Percent difference
AZ	$1,497,484	$10,149,955	578%
CA	$8,435,776	$20,834,106	147%
CO	$1,236,594	$50,235,060	3962%
ID	$3,252,841	$516,067	-84%
MT	$19,897	$6,862,105	34387%
NM	$1,116,057	$7,379,313	561%
NV	$124,960	$1,672,127	1238%
OR	$3,112,579	$24,845,976	698%
UT	$395,780	$21,856,306	5422%
WA	$8,842,926	$54,745,793	519%
WY	$28,182	$1,892,946	6617%

Table 5. Comparison of Outdoor Recreation Economies (ORE) among watersheds with boatable rivers in the western United States.

Percentiles	Average ORE for Low Density group	Average ORE for High Density group	Percent difference
10, 90	$8,894,062	$23,907,985	168.8%
20, 80	$15,257,978	$15,917,904	4.3%
25, 75	$13,833,220	$15,913,483	15.0%

In addition, we assessed ORE differences focusing on unmodified rivers. Interestingly, we found that ORE values were greater on average for watersheds with low density of unmodified rivers than compared to higher density watersheds (Table 6). These findings are in contrast to those based on densities of all (i.e. modified and unmodified) rivers both for all size classes (Table 3) and for boatable rivers (Table 5). In other words, watersheds with a higher density of unmodified river segments tend to have less outdoor recreation value than those with a lower density of unmodified rivers. Although these results may seem counterintuitive, it is suspected that, all other things being equal, watersheds with higher densities of unmodified rivers would tend to have lower densities of modified rivers (i.e. development). Thus, we suspect that, because outdoor recreation relies to some degree on having access (e.g., roads, put-in's) and other infrastructure (e.g., dams) that supports some forms of outdoor recreation while at the same time contributes to river modification, the contribution of undeveloped rivers to the outdoor recreation economy may be partially confounded by this relationship.

Table 6. Comparison of Outdoor Recreation Economies (ORE) among watersheds in the western United States with river densities defined in terms of all, unmodified river and stream segments.

Percentiles	Average ORE for Low Density group	Average ORE for High Density group	Percent difference
10, 90	$17,538,155	$8,343,551	-52.4%
20, 80	$16,495,832	$10,619,260	-35.6%
25, 75	$18,231,565	$10,279,915	-43.6%

Literature Cited

Outdoor Industry Association. 2017. The Outdoor Recreation Economy. Accessed at: https://outdoorindustry.org/wp-content/uploads/2017/04/OIA_RecEconomy_FINAL_Single.pdf

Appendix B: Analyses of altered rivers and streams in protected and unprotected areas of the western US, within and across ownerships.

Methods

The purpose of this analysis was to investigate how the degree of river modification (i.e. 'alteration') differs on average between protected and unprotected areas of the western US. Protected river and stream flowlines are defined as the portion of any flowline (i.e., river or stream segment) that intersects a Protected Area Database (PAD U.S. version 1.4) polygon with a GAP status of 1 or 2. GAP status 1 and 2 represents protected areas that are managed for biodiversity. Unprotected river and stream flowlines are defined as any portion of a flowline that does not intersect a PAD polygon with a GAP status of 1 or 2. For the purposes of this analysis, we restricted unprotected flowlines to only include flowlines that were less than or equal to 3 km from the nearest protected areas. Using the 3-km distance threshold adjusts for the disproportionate length of protected vs unprotected flowlines and spatial pattern of protected areas within the study area. The 3-km threshold approximately represents the 25th percentile of the distribution of river distances from protected areas. We computed a length weighted average river modification statistic for protected and unprotected flowlines. We also computed the weighted average river modification grouping by general land owner/ manager class. Protected and unprotected flowlines were assigned an ownership / manager class by extracting the PAD manager name class to the flowline midpoint. PAD manager name classes were generalized into the following ownership/management classes: U.S. Forest Service (USFS), Bureau of Land Management (BLM), National Park Service (NPS), federal other, non-federal other, state, and private.

Results

On average, modification of unprotected river and streams was roughly 2 times higher than protected rivers and streams, and this relationship was robust to the scale of analysis (Table 1). River modification on all non-federal lands was roughly 260% greater compared to all federal lands regardless of protection status (Table 2). Federal lands contain over 100,000 km of rivers and streams on protected lands constituting 90% of the total protected rivers and streams length within the western US (Table 3). Looking across general land ownership and management classes we see differences in the magnitudes of river modification that generally support the hypothesis that unprotected rivers and streams have higher average river modification scores (Table 4). A list of protected area designation types for GAP status 1 and 2 is provided in Table 5.

Table 1. Length weighted average river modification score for protected and unprotected rivers and streams. We computed the average river modification for unprotected streams at various distances from protected land. Distance to nearest protected land thresholds represent values corresponding to the 25th percentile (3 km), median (7 km), mean (10 km), and all unprotected rivers and streams.

Protected	Unprotected 3 km	Unprotected 7 km	Unprotected 10 km	All unprotected
9.0	21.5	21.0	20.5	19.9
Percentage ratio (Unprotected / Protected)	*239%*	*233%*	*228%*	*221%*

Table 2. Length-weighted average river modification score for federal and non-federal. Columns 1 to 3 (left to right) subset federal and non-federal lands by protection status and column 4 and 5 give the average river modification based solely on federal and non-federal ownership.

Ownership	Unprotected 3km	All unprotected	Protected	Combined protected and unprotected river modification score	Combined protected and 3km unprotected river modification score
Federal	11.1	10.7	7.7	9.81	9.02
Non-federal	30.4	25.6	20.1	25.48	28.98
Percentage ratio (Unprotected / Protected)	*274%*	*231%*	*181%*	*260%*	*321%*

Table 3. Total river and stream length (in kilometers) for federal and non-federal lands by protection status, including a 3-km threshold applied to unprotected lands.

Ownership	Unprotected 3km	All unprotected	Protected
Federal	66,328	249,464	107,566
Non-federal	77,816	400,545	12,376
Total Length	*144,145*	*650,008*	*119,942*

Table 4. River modification and total river and stream length by general PAD version 1.4 ownership and management class. For this analysis 'unprotected' is defined as flowline segments with a GAP status not equal to 1 or 2 and within 3-km Euclidean distance from the nearest GAP 1 or 2 protected area. * The 'Federal other' ownership class includes lands owned or managed by U.S. Fish and Wildlife Service, Department of Defense, Department of Energy, and Army Corps of Engineers. **The 'Non-federal other' ownership class includes regional, county, city, and tribal lands.

Ownership	**River modification (unprotected)**	**River modification (protected)**	**Length (km; unprotected)**	**Length (km; protected)**
BLM	16.4	13.6	11,873	13,798
NPS	27.9	7.8	4,18	19,208
USFS	9.3	5.8	52,565	70,966
Federal other*	27.4	23.8	1,472	3,595
Non-federal other**	28.9	20.0	6,984	5,342
Private	31.8	28.4	64,092	1,057
State	18.3	18.7	6,740	5,976
Total			*144,145*	*119,942*

Table 5: Number of protected areas in GAP status 1 and 2.

Protected area designation type	GAP status 1 number of designations	GAP status 2 number of designations
Wilderness Area	600	624
Marine Protected Area	114	184
State Conservation Area	52	1278
Research Natural Area	46	364
National Park	38	20
Area of Critical Environmental Concern	36	464
State Park	32	279
Private Conservation	30	1541
National Wildlife Refuge	29	190
National Monument or Landmark	22	26
Local Conservation Area	17	662
Wilderness Study Area	9	0
State Resource Management Area	8	24
Unknown	8	103
Conservation Easement	5	2673
Conservation Area	3	168
Approved or Proclamation Boundary	2	7
Historic or Cultural Area	2	10
Historic or Cultural Easement	2	1
Local Historic or Cultural Area	1	1
Local Park	1	60
Private Recreation or Education	1	0
Special Designation Area	1	3

State Recreation Area	1	423
Watershed Protection Area	1	29
Federal Other or Unknown	0	2
Local Other or Unknown	0	1
Local Recreation Area	0	93
Local Resource Management Area	0	9
Mitigation Land or Bank	0	2
National Lakeshore or Seashore	0	3
National Recreation Area	0	8
National Scenic, Botanical or Volcanic Area	0	6
Other Easement	0	21
Private Forest Stewardship	0	1
Private Historic or Cultural	0	0
Private Other or Unknown	0	3
Private Recreation or Education	0	129
Recreation Management Area	0	5
Recreation or Education Easement	0	5
Research or Educational Area	0	14
Resource Management Area	0	22
State Historic or Cultural Area	0	5
State Other or Unknown	0	1
State Wilderness	0	1
Wild and Scenic River	0	269