Wilderness Areas and the Flow of Surface-Water-Based Ecosystem Services

Model Approach and Value Estimates for Two Case Studies

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Abbreviations

ARIES: Artificial Intelligence for Ecosystem Services

BLM: Bureau of Land Management

CN: Curve Number

DEM: Digital Elevation Model

HUC: Hydrologic Unit Code

NAICS: North American Industry Classification System

NLCD: National Land Cover Dataset

SRTM: Shuttle Radar Topography Mission

Introduction

A major gap in the Wilderness economics literature exists regarding how and by how much the economic value of designated Wilderness differs from the economic value of "nature" or "protected areas" or "public lands” in general. To begin to address this gap and to suggest a path for future research into the question, we develop and implement a model of water-based or water-derived ecosystem services for two case study landscapes, both of which include significant wilderness and non-wilderness public lands, as well as private lands. In brief, we use a coupled hydrological-human model to generate estimates of surface water flows and related ecosystem service values in the San Pedro watershed in Arizona and in the region surrounding the Pisgah National Forest in western North Carolina.

The utility of an ecosystem-service-based approach is underscored by the incorporation of ecosystem services into U.S. Department of Agriculture Forest Service (USFS) (USDA Forest Service, 2012) and U.S. Bureau of Land Management (BLM) (Bureau of Land Management, 2016) planning. The new USFS planning rule, for example, seeks to ensure that National Forest System lands “provide people and communities with ecosystem services and multiple uses that provide a range of social, economic and ecological benefits for the present and into the future (26 CFR 219.1(c))”. It defines ecosystem services as “benefits people obtain from ecosystems”, which is adequate for expressing the overall idea. To break down the processes by which ecosystem deliver those benefits to people, however, we prefer a more robust definition:

> “Ecosystem services are the effects on human well-being of the flow of benefits from ecosystems to people over given extents of space and time (Johnson et al 2010)”.

This definition both clarifies that ecosystem services, ultimately, impact human welfare (as opposed to water, timber, fish, or other biophysical quantities) while stressing that those impacts arise from a tangible, connected landscape of biophysical reality. As described in the Methods section below, our modeling approach incorporates both the demand for (effects on human welfare) and a supply of (flow from ecosystems to people) benefits people obtain from nature.

Because our approach is spatially explicit, we are able to compare benefit flows from areas that are designated as wilderness to other parts of the landscape. While a more complete investigation of the full suite of ecosystem services provided by wilderness areas would provide a more reliable distinction between wilderness and other lands, this effort is focused solely on the benefits associated with surface water use. That biophysical reality is fairly well understood and documented, making it possible to map and track the movement of water from the places it enters the landscape (as precipitation) to the places where it provides benefits to various human endpoints (through consumption or use).

Where possible, we connect water supply to economic measures (including monetary valuation) of impacts on human welfare. In other cases, such as with sportfishing, the available data do not allow as solid a connection to the "specific space(s) and time(s)" over which the benefit is conveyed from the ecosystem to the human system. In those cases, we note the extent of potential connection(s), without explicit quantification.

Case Study Locations

Surface-water runoff models were implemented in two ecosystems--one in the southwest United States (the San Pedro watershed) and the other in the southeast United States (in the area surrounding the Pisgah National Forest). These study areas include a mix of land ownership (public and private) and a diversity of demands for water, including recreation, agriculture, industrial, and domestic water uses.

In North Carolina, the study region (see Figure 1-A) consists of all HUC 12's within the 13 counties that intersect the Pisgah National Forest Proclamation boundary. There is substantial surface-water demand to support residential, industrial, agricultural (livestock, irrigation, and aquaculture) and recreational activities. The watershed features three wilderness areas, including the Linville Gorge Wilderness, Middle Prong Wilderness, and the Shining Rock Wilderness, and a single National Forest, the Pisgah National Forest. Approximately 1.1% of the study area is designated as wilderness, and more than 32% is within the National Forest, with the bulk of the remaining lands held in private ownership. Nearly 69% of the study area is covered by deciduous forest. In addition, the study area includes pasture and hay (9%) , developed open space (8.3%) and evergreen forest (5.3%), with the remaining area comprised of mixed forest, low intensity development and herbaceous land covers.

The San Pedro watershed (see Figure 1-B) spans the US-Mexico border, and a majority of its water supply comes from groundwater. However, surface water is used for irrigated agriculture and mining in the region, and the purchase of water rights by The Nature Conservancy to protect in-stream flows in the lower San Pedro support multiple recreation-based activities. The watershed features four wilderness areas, including: Galiuro Wilderness, Miller Peak Wilderness, Santa Teresa Wilderness, and Rincon Mountain Wilderness (with the latter three of these maintaining a provisional status), and a single National Forest, the Coronado National Forest. Together these Wilderness Areas and National Forest lands represent 3.8% and 10.1% of the total watershed area, respectively. The remaining lands are a mix of other public (e.g. BLM, state lands) and private ownership. The bulk of the study area, nearly 88%, is comprised of scrub/shrub land cover type. Evergreen forest makes up approximately 7.75% of the total land area, with the remaining areas consisting largely of developed open space and herbaceous land cover types.

Figure 1-A: North Carolina Study Region-HUC 8, National Forest and Wilderness Area boundaries.

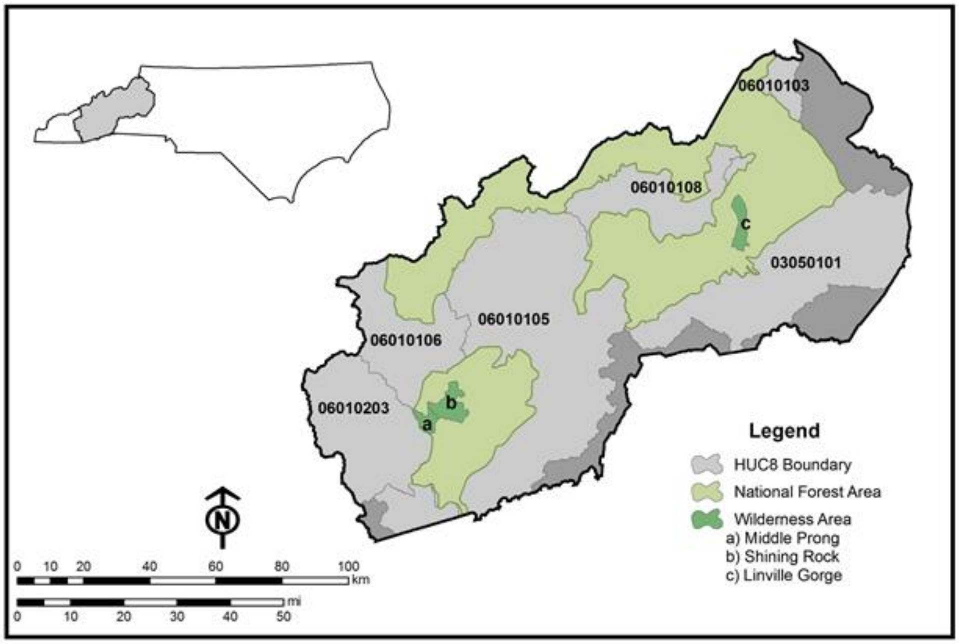
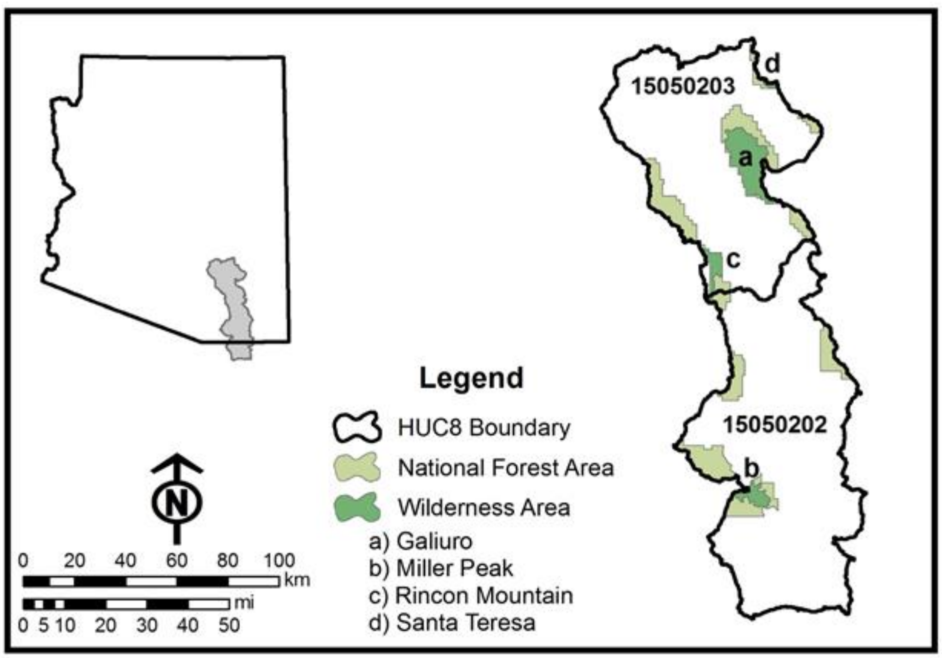


Figure 1-B: Arizona Study Region - HUC 8, National Forest and Wilderness Area boundaries.



Sources: HUC 8 boundaries, National Forest and Wilderness boundaries, and Federal land boundaries were all obtained from The National Map (https://nationalmap.gov/).

Methods

We modeled surface water flow (i.e. potential supply) in the Pisgah–Nantahala National Forest region of western North Carolina and the San Pedro watershed in southwestern Arizona using the Artificial Intelligence for Ecosystem Services (ARIES) modeling platform (Villa et al, 2014). The ARIES modeling approach partitions the landscape into source, sink, and use locations, all of which are connected through flow paths (which vary depending on the type of ecosystem service being modeled) (Figure 2). Source locations are those which provide a potential benefit to a human end-user (i.e. beneficiary), while sink locations are natural landscape features which deplete (or eliminate) the flow of an ecosystem service through a particular location. Use locations denote the accrual of a benefit to a specific end-user (e.g. residence, farm). A flow path represents the transport/movement of matter, energy, or information between source and use locations. In the case of surface water, the flow path represents the horizontal movement of water across the landscape (biophysical flow of matter and energy), while the flow path for aesthetics represents the transfer of information along a line of sight (e.g. between a viewpoint and the landscape it overlooks). An area of critical flow is a location through which a relatively large amount of an ecosystem service flows.

Figure 2: Conceptual diagram of the ARIES modeling framework (Villa et al, 2014).

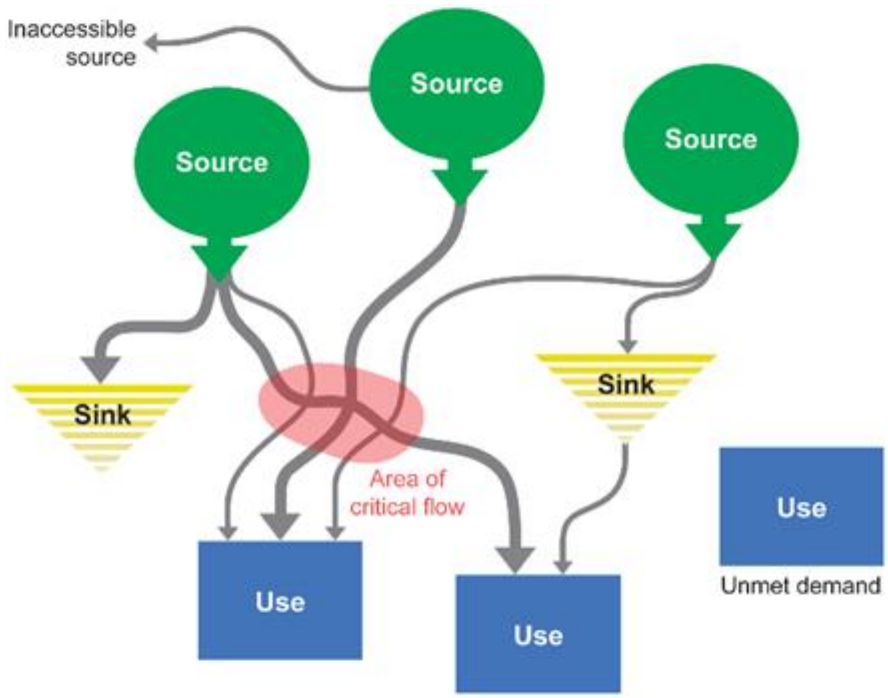
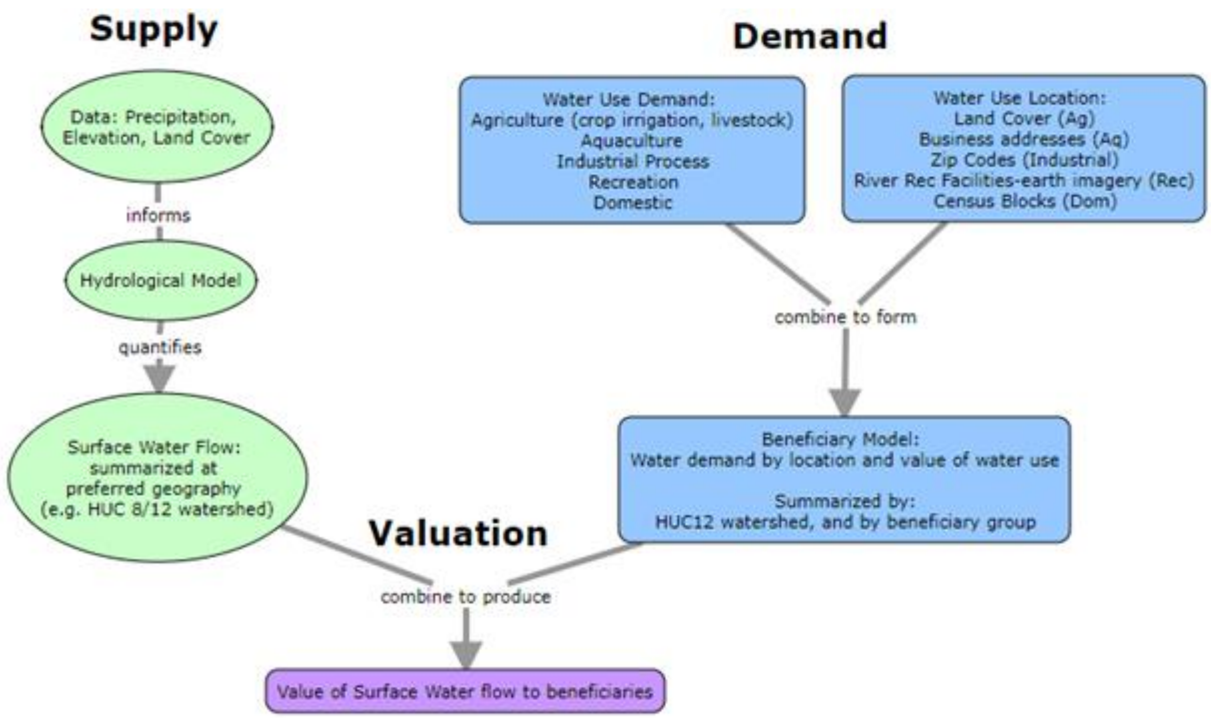


Figure 3: Data resources and processing workflow for surface water flow analysis.



Surface Water Flow

We modeled horizontal surface-water flow using the USDA Natural Resources Conservation Services Curve Number (CN) method (USDA, 1986) developed and implemented in ARIES. The model considers land cover and hydrologic soils group data to estimate a curve number whose value represents the runoff potential across the area of investigation. The curve number ranges from 30 to 100, where low numbers (e.g. forested areas) imply a lower runoff potential and high numbers (e.g. urban areas) imply a higher runoff potential (see Table 1).

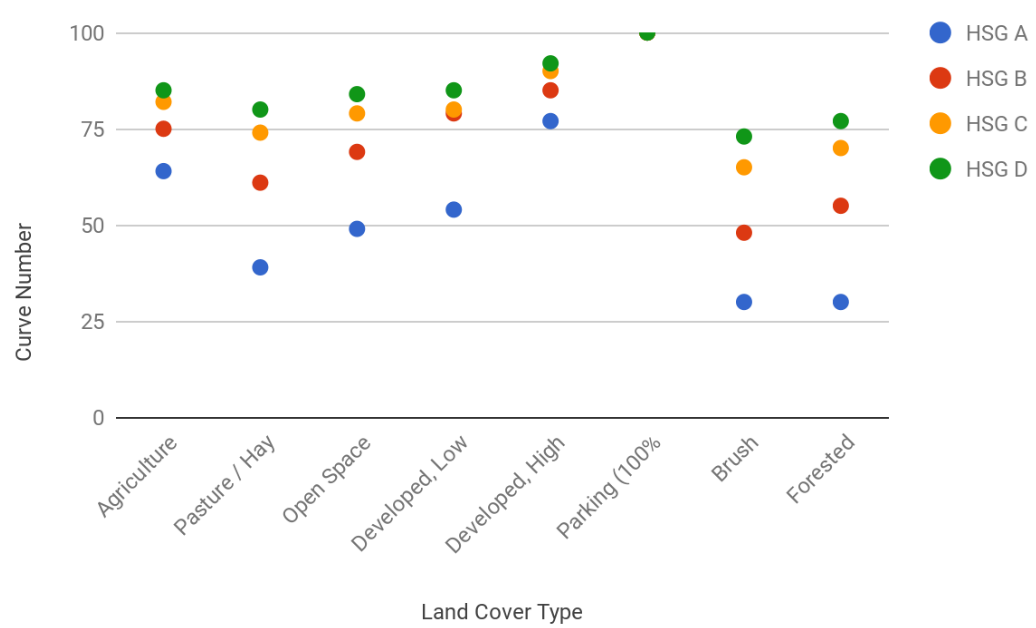
A model for each HUC8 was run at a 300-m spatial resolution for the period 1 January 2016 through 31 December 2016 on a one-day time step. We used the USGS National Land Cover Dataset (https://viewer.nationalmap.gov/) and the Natural Resources Conservation Service soils data (http://soildatamart.nrcs.usda.gov/) to populate the model. Additionally, data gathered from nearby weather stations are used to represent daily rainfall totals.

Once a study area boundary is defined, ARIES automatically derives the watershed boundary from a digital elevation model (DEM). This particular implementation of the model relies on the Shuttle Radar Topography Mission (SRTM) 90-m resolution data (USGS, 2006). The algorithm computes slope and aspect, derives stream locations, and then routes water horizontally across the landscape using the CN approach described above. The model outputs a spatially explicit time series of total precipitation, locally exchanged water volume, and total surface water

Table 1: Curve number values for land cover classes and their corresponding hydrologic soil group (modified from USDA TR-55, 1986). The numbers in parentheses represent the percent of the North Carolina and Arizona study areas (respectively) comprised of a soil type (column) - land cover type (row) combination. Values are rounded to the nearest percentage, and soil type - land cover type combinations representing less than 1% of the total study area are not included in the table.

Land Cover Type	HSG A	HSG B	HSG C	HSG D
Agriculture	64	75	82	85
Pasture / Hay	39 (NC: 1%)	61 (NC: 9%; AZ: 1%)	74 (NC: 1%; AZ: 1%)	80
Open Space	49 (NC: 1%)	69 (NC: 7%)	79	84
Developed, Low Density	54	79 (NC: 1%)	80	85
Developed, High Density	77	85	90	92
Parking (100% impervious)	100	100	100	100
Shrub / Scrub / Brush	30 (AZ: 4%)	48 (AZ: 24%)	65 (AZ: 27%)	73 (AZ: 32%)
Forested	30 (NC: 16%)	55 (NC: 56%; AZ: 1%)	70 (NC: 2%)	77 (NC: 1%; AZ: 7%)

Figure 4: Curve number values for land cover classes, by hydrologic soil group (HSG) types (modified from USDA TR-55, 1986).



runoff. Daily values are then aggregated over the duration of the model run to estimate an annual total.

Water Use Estimates

For the North Carolina study region, we estimated water usage in millions of gallons per year (Mgal/yr) for fresh, surface water at the HUC 12 scale for agriculture, aquaculture, recreation (boating and fishing), industrial, and domestic water use.[1] We relied heavily on data produced by the USGS National Water-Use Science Project which compiles and disseminates water-use data for the United States every five years. Unfortunately, geographically consistent water use data (i.e. data collected at the same spatial scale) does not exist for the study region. Instead we used geographical information systems (GIS) techniques to convert 2010 county-level water use data (U.S. Geological Survey, 2016) to HUC 12 scale estimates for the categories listed above, before eventually aggregating these estimates to the HUC 8 scale.

Agriculture

Cropland and Livestock Water Use

The 2010 USGS water use data estimates county level agricultural water use (surface water withdrawals) for cropland irrigation and livestock water use (USGS, 2016).[2] In order to obtain water use estimates for our desired geography, we computed the intersection between HUC 12

[1] See U.S. Geological Survey. (2016, December 9). Estimated Use of Water in the United States County-Level Data for 2010. Retrieved September 25, 2017, from https://water.usgs.gov/watuse/data/2010/.

[2] All irrigation water is freshwater and all withdrawals for livestock are self supplied, freshwater (USGS, 2014).

and county boundaries within the NC study region. The resulting polygons were then identifiable by both their county and HUC 12 membership. Next, we used the 2011 NLCD to determine the area of total crop- and pasture-land within each of these areas. These areal values were then used to calculate the proportion of crop- and pasture-land for each portion of a HUC 12 within a county. Lastly we multiply the derived proportion against the total county water usage to complete the water withdrawals computation for each HUC 12.

Aquaculture Water Use

Data from the North Carolina Wildlife Resources Commission and the North Carolina Department of Agriculture and Consumer Services allowed us to determine the location of aquaculture facilities and their corresponding HUC 12. The North Carolina Wildlife Resources Commission's Inland Fisheries Division operates six fish hatcheries across the state: two warm-water, one cool-water, and three cold-water hatcheries. Four of those hatcheries, all three cold-water hatcheries and the only cool-water hatchery,[3] are located within the NC study area (N.C. Wildlife Resources Commission, 2017). Staff at the Table Rock cool-water hatchery and the Bobby N. Setzer cold-water fish hatchery were contacted to obtain an estimate of their respective average annual surface water withdrawals.

The North Carolina Department of Agriculture and Consumer Services provides a list of private facilities that require a permit for aquaculture products within the state (North Carolina Department of Agriculture & Consumer Services, n.d.). In the study region, there were 13 additional aquaculture facilities that had up to date contact information. Each facility was contacted to obtain an estimate of annual surface water withdrawals. Seven of the facilities were able to provide this information. For the remaining facilities, including the two state run hatcheries we were unable to contact, we assumed their annual surface water withdrawals to be equal to the average withdrawal of all facilities for which we did have data.

Table 2. Aquaculture facilities by type and estimated water use.

Facility Name	Ownership	Water Use (Mgal/Yr)[a]
Table Rock Hatchery	State Run	427.1
Bobby N. Setzer State Fish Hatchery	State Run	1839.6
Armstrong State Fish Hatchery	State Run	863.3[a]
Marion State Fish Hatchery	State Run	863.3[a]

[3] The three cold-water hatcheries are Armstrong State hatchery and Marion State Fish Hatchery in McDowell County and Bobby N. Setzer State Fish Hatchery in Transylvania County. The cool-water hatchery is Table Rock Hatchery in Burke County.

Mountain Lake & Pond Management, Inc.	Private	0.0012
Buck Creek Trout Farm	Private	118.3
Cantrell Creek Trout Farm LLC	Private	365.0
Hump Mountain Trout	Private	157.7
Shadow Creek Trout	Private	394.2
North Fork Trout Farm	Private	1051.2
Sunburst Trout Farms	Private	3416.4
Moonshine Trout Adventure	Private	863.3[a]
Wolf Creek Campground	Private	863.3[a]
Morgan Mill Trout Farm LLC	Private	863.3[a]
Wayback Farms	Private	863.3[a]
Grandfather Trout Pond	Private	863.3[a]
EnergyXchange / Project Branch Out	Private	863.3[a]

[a] Unable to contact facility/facility staff did not respond to inquiry. Water demand equals the average surface water demand of responding facilities (863.3 Mgal/Yr).

Although the USGS water demand tables include aquaculture, they combine 2007 data for the number of aquaculture farms in operation by the county average surface water withdrawal rates for farms in the county (U.S. Geological Survey, 2014). The USGS data also assumes the change in the number of aquaculture farms in the county from 2002 to 2007 is representative of withdrawal changes from 2005 to 2007. As a result, we decided to use the information gathered through primary data collection instead of the data contained in the USGS water use tables.

Recreation

Fishing License Data

We acquired the number of licenses sold with a fishing privilege by zip code for the fiscal year 2016-2017 from the North Carolina Wildlife Resources Commision (NCWRC). The data includes 816,503 license sales in counties that intersect our study region and a corresponding home zip code of the licensee. However, many of the records contain a zip code not in our study region. These discrepancies could either be because an individual purchased their license as a resident and moved away, have a residence in a county in our study region as well as another state, or due to an error in the way the NCWRC system records zip codes that cross county lines.

For the purposes of this study, only licenses from the zip codes that intersect the study region were used. Once the data were filtered 202,007 licenses remained. In order to estimate the number of fishing licenses per HUC 8, the area of intersection between each HUC 12 and zip code was calculated. These area values were used to calculate the percent of each zip code within each HUC 12. Licenses were then allocated to each polygon by multiplying the percent area by the number of licenses in the zip code. Lastly, the total number of licenses per HUC 8 was computed by aggregating the number of licenses based on their HUC 8 membership.

Boating Access

Boating access points were identified from data available on the NC OneMap GeoSpatial Portal (NC WRC Division of Engineering and Lands Management, 2016) and from primary data collection. For the boat access points located via the NC OneMap, satellite imagery was used to evaluate the size of the surrounding parking lot and the level of surrounding development. Each site was assigned a high, moderate, or low use designation based on the satellite analysis.

The primary data collection effort was conducted by contacting outfitters and river guides along the French Broad River to determine frequently used sites and other popular drop-in points. Lastly, a map created by RiverLink (RiverLink, n.d.) was used to identify other less popular access points. In total, 31 boat access points, largely along the French Broad River, were identified.

Industrial Water Use

The 2010 USGS water use data (U.S. Geological Survey, 2016) details self-supplied, fresh, surface water withdrawals for industrial water use for each county in the United States. Unlike the 1995 data release, however, no information regarding publicly supplied industrial water use is provided. The 1995 data release included county-level data for total public water supply withdrawals, public water supply withdrawals from surface water, deliveries from the public water supply for industrial purposes, and the total surface-freshwater withdrawals for industrial water use. To overcome this limitation in the data, county-level publicly-supplied industrial water use (for 2010) was estimated using the same proportion of self-supplied to publicly supplied water that was recorded in 1995 (the last year for which this data is available).

Next, the water use data were combined with North American Industry Classification System (NAICS) business pattern data to determine employment and industrial water usage at the HUC 12 scale. NAICS data was extracted for all zip codes that intersect our 13-county study region. We were interested in understanding which industries use the most water; however, this data does not exist for the study region. Instead, we relied on a report that provides the weighted percent rank of the total market volume of water used in Southern California by 3 digit NAICS codes (U.S. Department of the Interior & Bureau of Reclamation, 2009) to estimate water use by industry type throughout the study region.

Using GIS, the zip code, HUC 12 and county boundaries were combined to determine their areas of intersection. Each resulting polygon was assigned a corresponding amount of industrial water usage based on their size and the composition of industrial employment. Finally, these values were aggregated to the HUC 8 scale for inclusion in the model.

Employment

The North American Industry Classification System (NAICS) categorizes business establishments based on the type of economic activity in which they engage (e.g. agriculture, manufacturing). The number of employees per establishment is presented as a value range with the following bins: 1 to 4, 5 to 9, 10 to 19, 20 to 49, 50 to 99, 100 to 249, 250 to 499, 500 to 999, and 1000+. We used the midpoint value as the actual number of employees of a particular establishment. The data was filtered to select only the industrial employment records. Next, the total number of industrial employees was computed by grouping the remaining records by county and aggregating the number of employees in those records. Finally, the disaggregation technique described above was used to compute the number of industrial employees within each HUC 12.

Domestic

The 2010 USGS water use data (U.S. Geological Survey, 2016) details self-supplied surface-water withdrawals and the amount of public water supply used for domestic purposes. No domestic surface freshwater is self-supplied in the NC study region. In order to estimate domestic water use for each HUC 12, the amount of publicly supplied domestic water deliveries was calculated[4]. Then, using the 2010 block group population estimates (U.S. Census Bureau, 2011), per capita water usage was computed. Finally, we used the disaggregation technique described above to derive the total publicly-supplied domestic water use for each HUC 12.

Results

The figures, maps, and tables below illustrate alternative spatial and temporal representations of model output. The model is run at a daily time step for an entire year at a 300-m spatial resolution. Model results are presented at the HUC8 scale, as each HUC8 watershed within the two study areas was modeled independently. The results presented below are for the 2016 calendar year, but the start and end dates for a model run can easily be adjusted (assuming there is corresponding weather station data for the time-period of interest). Similarly, the spatial resolution can be decreased for rapid prototyping of additional model functionality or increased when a greater level of detail is desired. It should be noted, however, that there is an

[4] In order to determine what amount of publicly supplied domestic deliveries would be from surface water, we multiplied the same percentages from the 1995 USGS data for industrial public water supply surface water calculations to the domestic water use data.

inherent trade-off between model resolution and the costs associated with achieving increasing specificity (e.g. model run-time, computational resources, data suitability).

Results are presented at three spatial scales, each with their own potential to inform land management and decision making. The first (shown in Figure 5) is a hydrograph for the duration of the model run (on a daily time-step) that quantifies the amount of surface-water runoff that passes through the watershed outlet each day. The chart represents the hydrologic response to a precipitation event as the surface runoff moves through the watershed towards the outlet, and is useful for tracking large storm events, potential recharge to public water supply systems and an early warning indicator of potential water supply shortages for drought-prone regions. A cursory review of the two hydrographs illustrates the marked differences in ecosystem characteristics between the two case study regions. HUC8 - 06010105 (in North Carolina) experiences numerous, significant runoff periods distributed throughout the year, while the San Pedro experiences the bulk of its peak flow in the fall.

Next, we present mapped outputs of total precipitation and surface water runoff at the spatial resolution of the model (300-m). Figures 6-A and 6-B display modeled outputs for the North Carolina and Arizona case studies, respectively. The left panel of each figure represents annual precipitation (in mm), while the right panel represents the total surface water runoff (in mm) aggregated over the time period 1 January 2016-31 December 2016. For each of the images, light blue hues are used to depict low values and dark blue hues are used to depict high values. In general, higher precipitation values in the NC study region tends to be associated with high elevation areas (which is also where the majority of the wilderness areas within the study region are located). The abrupt changes in values in both of the precipitation maps (i.e. linear features) is a result of the interpolation process merging data from different weather stations. From this, it is evident that a smoothing algorithm should be applied to precipitation data prior to its inclusion in the surface-water runoff model. This functionality will need to be further-developed in ARIES in order to fully automate the modeling process (a primary goal in the development of the ARIES modeling platform). In the right panel of each of these figures the major rivers become easily identifiable while the runoff values of the remainder of the landscape are closely associated with the spatial arrangement of the various land cover types.

Figure 5-A: Daily surface water runoff in NC HUC8 - 06010105 for the period 1 January 2016-31 December 2016 measured in mm/day.

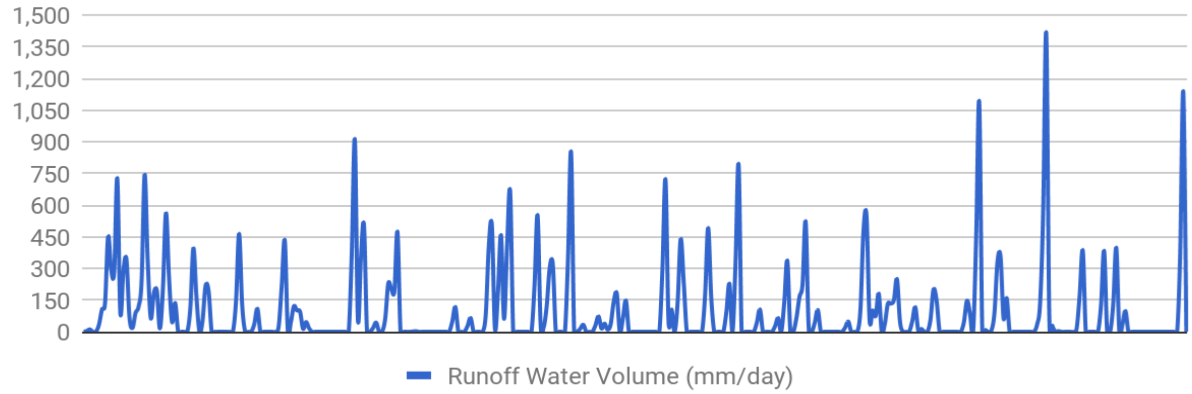


Figure 5-B: Daily surface water runoff in the San Pedro watershed (AZ HUC8-15050202 & 15050203)

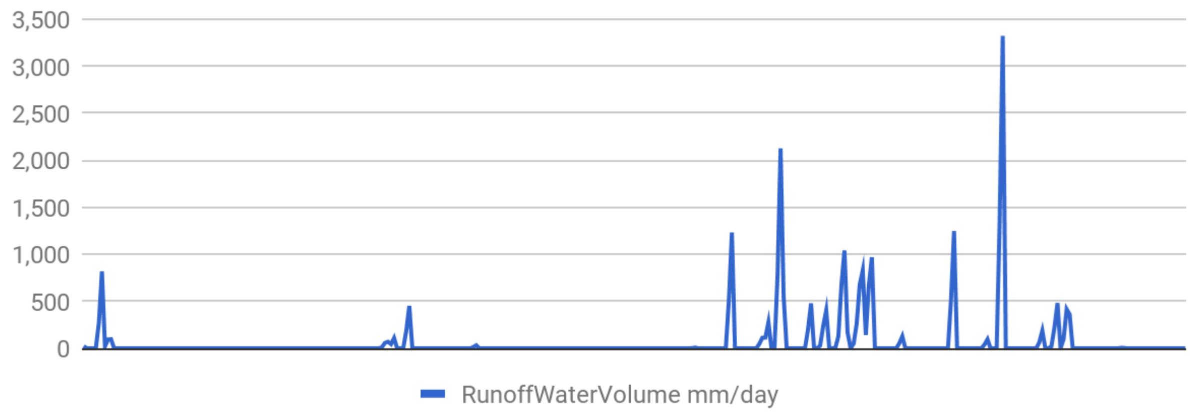


Figure 6-A: Modeled outputs for the area of NC HUC8-03050101 surrounding the Linville Gorge Wilderness Area. A) Total annual precipitation (mm/yr). B) Total surface water runoff (x10^3 mm/yr)

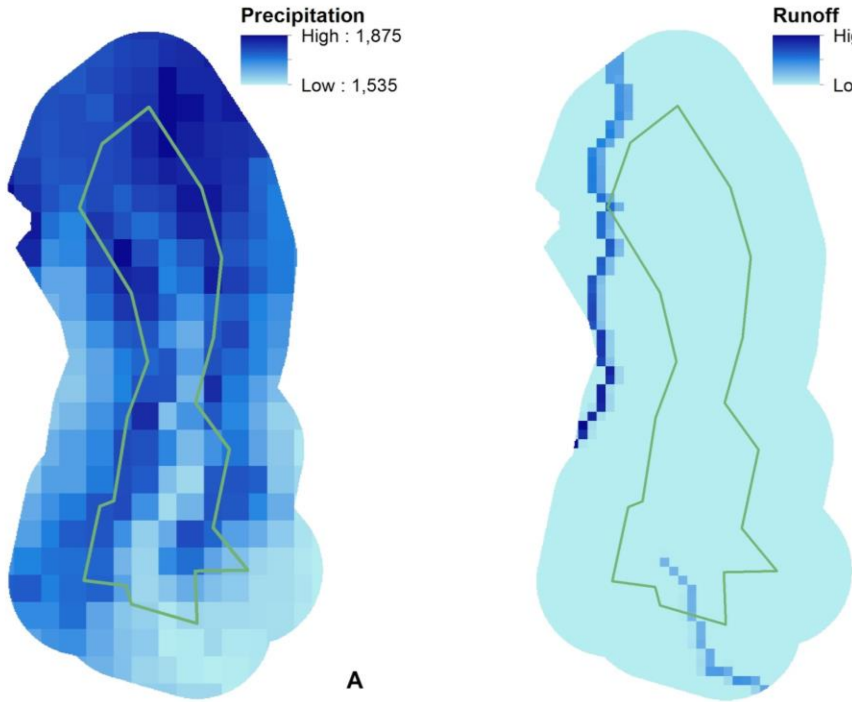
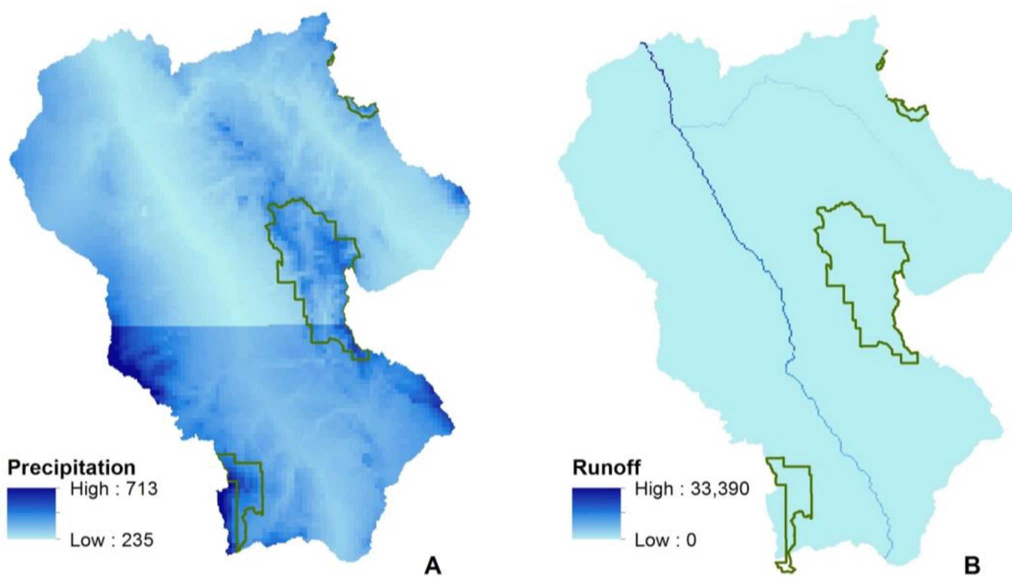


Figure 6-B: Modeled outputs for the San Pedro watershed (AZ HUC8-15050203) surrounding Galiuro, Rincon Mountain and Santa Teresa Wilderness Areas. A) Total annual precipitation (mm/yr). B) Total surface water runoff (x10^3 mm/yr).



Tables 3-A through 3-G summarize total demand and supply within each of the study watersheds. The upper portion of the table details surface water demand for each of the following categories: residential, industrial, agriculture, and aquaculture. For each of these demand categories, we have quantified demand in million gallons per year and presented additional metrics to describe the number of people, facilities, or acres that are supported by surface water flows. In addition, we detail two aspects of recreation, boating and fishing, and quantify the number of public access points (boating) and total number of license holders (fishing) within the watershed. These recreation metrics likely represent a lower bound on the number of beneficiaries given that there are private lands adjacent to public waterways (that may include docks, ramps, or other river access points) and the ability to fish anywhere in the state with a proper license (e.g. license holder is not restricted to their home watershed). The lower portion of the table details surface water supply values that were modeled in ARIES as surface-water runoff. These data were used to derive the water supply values by aggregating the per pixel values within three boundary types: 1) Wilderness Areas, 2) National Forest lands, and 3) Other lands (comprised of all other public and private lands within a HUC8 watershed).

Table 3-A. Supply and demand characteristics for NC HUC8-03050101

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)
Residential	2,990.30	204,703 (people)
Industrial	5,677.31	71,306 (jobs)
Agriculture (Crops)	5,965.46	432.81 (ha)
Agriculture (Livestock)	62.63	28,042.74 (ha)
Aquaculture	2,272.00	4 (facilities)
Recreation (Boating Access)		8
Recreation (Fishing Licenses)		10,767
Supply Category	**% Area**	**% Supply**
Wilderness Area	0.85%	0.02%
National Forest	21.30%	2.16%
Other	77.85%	97.82%

Table 3-B. Supply and demand characteristics for NC HUC8-06010103

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)

Residential	217.48	21,366 (people)
Industrial	139.28	6,730 (jobs)
Agriculture (Crops)	276.23	30.33 (ha)
Agriculture (Livestock)	18.75	5,405.04 (ha)
Aquaculture	1021.00	2 (facilities)
Recreation (Boating Access)		0
Recreation (Fishing Licenses)		10,627
Supply Category	**% Area**	**% Supply**
Wilderness Area	0%	0%
National Forest	16.55%	4.27%
Other	83.45%	95.73%

Table 3-C. Supply and demand characteristics for NC HUC8-06010105

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)
Residential	5,859.48	387,434 (people)
Industrial	2,678.52	152,972 (jobs)
Agriculture (Crops)	4,137.57	2,738.79 (ha)
Agriculture (Livestock)	121.42	49,561.83 (ha)
Aquaculture	6239.90	7 (facilities)
Recreation (Boating Access)		15
Recreation (Fishing Licenses)		152,925
Supply Category	**% Area**	**% Supply**
Wilderness Area	0%	0%
National Forest	29.50%	20.26%
Other	70.50%	79.74%

Table 3-D. Supply and demand characteristics for NC HUC8-06010106

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)

Residential	985.28	55,626 (people)
Industrial	10,651.3	15,485 (jobs)
Agriculture (Crops)	222.87	487.53 (ha)
Agriculture (Livestock)	47.53	12,090.06 (ha)
Aquaculture	3416.4	1 (facilities)
Recreation (Boating Access)		0
Recreation (Fishing Licenses)		9,576
Supply Category	**% Area**	**% Supply**
Wilderness Area	5.96%	0.31%
National Forest	24.91%	30.30%
Other	69.13%	69.39%

Table 3-E. Supply and demand characteristics for NC HUC8-06010108

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)
Residential	238.22	42,206 (people)
Industrial	252.98	8,935 (jobs)
Agriculture (Crops)	1,630.63	113.22 (ha)
Agriculture (Livestock)	32.79	12,194.73 (ha)
Aquaculture	1726.6	2 (facilities)
Recreation (Boating Access)		0
Recreation (Fishing Licenses)		7,938
Supply Category	**% Area**	**% Supply**
Wilderness Area	0%	0%
National Forest	21.14%	5.80%
Other	78.86%	94.20%

Table 3-F. Supply and demand characteristics for NC HUC8-06010203

Demand Category	Demand Quantity (Mgal / yr)	Other Metric(s)

Residential	14.16	40,155 (people)
Industrial	87.93	10,711 (jobs)
Agriculture (Crops)	164.25	36.81 (ha)
Agriculture (Livestock)	7.02	4,280.94 (ha)
Aquaculture	0.0012	1 (facilities)
Recreation (Boating Access)		8
Recreation (Fishing Licenses)		466
Supply Category	**% Area**	**% Supply**
Wilderness Area	0.03%	0%
National Forest	0.07%	0%
Other	99.89%	100.00%

Table 3-G. Supply characteristics for AZ HUC8-15050202

Supply Category	% Area	% Supply
Wilderness Area	1.19%	0%
National Forest	9.18%	0.13%
Other	89.63%	99.87%

Table 3-G. Supply characteristics for AZ HUC8-15050203

Supply Category	% Area	% Supply
Wilderness Area	7.06%	0.06%
National Forest	11.24%	0.08%
Other	81.70%	99.86%

Discussion

Limitations of the modeling approach

This project set out to develop and implement an approach to quantifying surface water flows from wilderness areas to human endpoints that could easily and rapidly be replicated in other geographies and ecosystem types. During the course of our effort, we have identified a number of data and modeling limitations that need resolution in order to fully realize the potential of our proposed approach as a tool that can facilitate improved land management and decision-making.

1. Data availability: Our approach utilized both publicly available data (from the USGS Water Use Tables) and survey data (for specific beneficiary types in North Carolina). We found that although the USGS Water Use Tables were useful for defining surface water demand, the data is aggregated to such an extent that it is less useful for exploring impacts to specific industries of importance within a given study area. Changes to the water use tables over time (e.g. data collection methods, data sources used and aggregation levels) limit the utility of this data source for long-term temporal modeling of water demand. In addition, these data are released on a five-year time interval, further complicating efforts to achieve greater temporal resolution in modeled outputs. We conducted our own survey of water use for priority industries within the North Carolina study region, but this effort is time consuming and not always guaranteed to provide the desired outcomes (e.g. sufficient response rates to inquiries). Lastly, as discussed in other sections of the report, the geographic disparities in data, ranging from individual users to aggregate values for counties, watersheds and zip codes, necessitate an approach that involves both data aggregation and disaggregation to reach a common geographic scale for all data resources. Until a high-resolution data source on water demand exists, any effort to quantify these types of benefits will require some level of aggregation that masks the behaviors of individual actors (e.g. households, farms, businesses), thereby limiting our ability to develop a true, agent-based modeling approach.
2. Groundwater: The lack of consistent, reliable, national-scale groundwater data presents a number of modeling challenges. Without a groundwater model, it is difficult to compute a base flow condition. While our approach masks this limitation by aggregating data over a single year, the lack of baseflow representation in the model makes it impossible to increase the temporal resolution to a level that can properly support management decisions (i.e. daily or weekly). In addition, the lack of a groundwater model results means that we are not able to fully account for the value of water that

serves to recharge underground aquifers which eventually surface in some other location via springs.

3. Model calibration: The CN approach to modeling surface water flow offers opportunities for model calibration in locations with appropriate supporting data (e.g. a stream gauge at the watershed outlet). It may be possible in future iterations of the ARIES software to guide the user through the calibration process through the use of artificial intelligence and data-mining techniques. As it stands, model calibration is a time-consuming effort that lies beyond the scope of this project, but is still a necessary step to ensuring model accuracy and land management relevance.
4. Snapshot or long-term trend: Our approach quantifies surface-water runoff and demand aggregated over single year (2016). There are two worthwhile directions to head from this starting point, each with different endpoints and applications. First, it may prove useful to compute an average condition that considers a longer-term record of both precipitation and demand. This would, necessarily, involve running the supply model over an extended time period, and coupling supply with demand over this period to quantify shortages and/or surpluses. Second, and likely more relevant in locations where water scarcity is more pressing, is the ability to provide results more frequently than the annual outputs presented here. Again, from the supply-side of the equation this is possible, and in fact, was already done here (prior to daily results being aggregated to annual values). However, there is no consistent, nationally available demand-side data to support this level of temporal resolution.

Ecosystem benefits and/or impacts on human welfare that were not considered

There were ecosystem benefits and impacts on human welfare that we established as important to acknowledge, however, due to data limitations, we were ultimately unable to evaluate the full extent of the connection between the benefit conveyed from the ecosystem to the human system. These activities include trying to estimate the surface water usage from breweries in the region to water related recreational activities such as fishing and boating.

While surface water use from some breweries may be accounted for in our industrial water use breakdown, we originally wanted to separately examine the brewery scene in our study region (which mostly focused in and around Asheville). Asheville, one of the largest cities in our study region, is heralded as one of the craft brewery capitals of the east coast. Many larger craft brewing operations such as Sierra Nevada, Oskar Blues, or New Belgium, opened distribution centers in and around the city largely due to the promise of available, high quality water for the brewers. We originally wanted to obtain primary surface water data related to how much water a specific brewery was intaking for their use and from where, however, so few breweries responded we had to abandon this method of data collection.

We then shifted focus to other recreation activities, such as fishing and the geographic connection between wilderness and who is fishing where. We acquired the number of licenses sold with a fishing privilege broken down by zip code from The North Carolina Wildlife Resources Commision and visitor use data from the U.S. Forest Service's National Visitor Use Monitoring program (NVUM). Because the NVUM combines data for both the Nantahala and the Pisgah National Forests we could not definitively breakdown the the relationship between the number of people with fishing licenses in our study region and how they benefit from wilderness in just the Pisgah National Forest.

However, from the visitor use data we know that fishing is the 10th most participated in activity listed by survey participants, 53% of visitors to the combined National Forests reside between 0 and 50 miles away, and 13 of the 15 most commonly reported zip codes of residency from visitors to Wilderness are from our 13-county study region. We can interpolate that people choosing to fish in the National Forest most likely reside in our study region.

Another water related recreation activity we measured data for but did not directly connect back to water use was boating access points and areas of high use along the French Broad River. The main focus for this data was to try and determine important points along waterways within our study region where we could examine how people/residents were using the river for recreation or the frequency of access at these points.

In a more expanded version of the study, it would be interesting to look at how the most used access points along downstream waterways (not just on the French Broad) are hydrologically connected to surface water flows originating from Pisgah Wilderness and how users of those downstream points value quality and quantity of water use. From conversations with local outfitters and guides, use of the French Broad River for activities such as tubing, paddleboarding, and other "day-trip" activities have increased substantially in the past 10 years. This is partially due to Asheville becoming a destination city for tourists due to its proximity to the National Forests, ease of access to water related recreation, and nationally recognized craft beer scene. As the region becomes increasingly tied to industries and recreation activities that are highly dependent on water quantity and quality, understanding the connection between the "extents of space and time" at which the benefit is conveyed from the ecosystem to the human system becomes even more important.

Water quality

The effort described here outlines an approach to modeling water quantity, without consideration of the quality of the water being delivered. It is widely acknowledged that wilderness areas, due to their limited anthropogenic modification and their location surrounding headwater streams, provide a disproportionate amount of high quality water (Johnson and Spildie, 2014) to downstream urban (and urbanizing) areas. Although the development of a water quality model was outside the scope of this project, it remains an important next step for fully capturing the economic contributions that wilderness areas provide in regards to water resources.

Groundwater

We have focused here on surface water for the simple reason that there are more complete data on where surface water originates and better models to tell us where it goes within the system. Water that falls as rain within the boundaries of a wilderness area and stays on the surface (i.e., neither evaporating or infiltrating) will move downhill and, eventually, add to surface water supply outside the wilderness area. Water that infiltrates, could, on the other hand, move below the surface beyond the wilderness boundary and re-emerge on the surface in a spring, or it could be pumped from a well. Were we to count the benefit of that water use where it occurs, we would underestimate the benefits of "wilderness water".

The lack of consideration of groundwater is a greater limitation in the San Pedro watershed than it is in the Pisgah National Forest region, where groundwater withdrawals comprise just 2.5% of all daily water use. The San Pedro example does highlight the importance of adding groundwater usage data and modeling if the approach we have piloted here is to be generalized for use in diverse settings.

Future Research

At the outset of this project, we envisioned comprehensive mapping and value estimation for a full suite of ecosystem services. We wanted to measure fiber and fly fishing, hiking and hydropower, irrigation and inspiration, and to evaluate the extent to which wilderness contributes to human welfare at a landscape scale. As in much research however, we encountered a paucity of data and model limitations the correction of which was beyond the scope or capabilities of this pilot project. We have provided a proof of concept that should prove useful for guiding future data collection and refinement efforts, and identifying additional modeling capabilities necessary to develop additional biophysical models, including of how groundwater, wildlife, and human users move across wilderness and non-wilderness portions of the landscape would be fruitful.

We particularly recommend three avenues for future investigation and effort:

- Developing groundwater flow models for use in landscapes, such as the San Pedro, where groundwater represents a larger portion of water use.

- Improving National Visitor Use Monitoring and other recreational use data, perhaps by establishing a clearinghouse of use data that includes where, more precisely use occurs, and where the user resides.
- Application of the ARIES-based modeling approach used here to further landscape types, including coastal, marine, grasslands, et al.

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