Freshwater Resources in Designated Wilderness Areas of the United States: A State-of-Knowledge Review

WILDERNESS 50 years 1964–2014 YOURS: TO ENJOY TO PROTECT

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Abstract

Clean water is essential for ecosystem processes and for the maintenance of human populations. However, fresh water accounts for less than three percent of the world's total water volume. Numerous anthropogenic and natural processes impact the quality and quantity of the available resource. The value of high-quality water will likely increase as threats to water resources expand and human demands increase. In the United States, public lands such as forests and grasslands often contain watersheds that have been minimally modified by human disturbances. Wilderness areas in particular often provide disproportionately large volumes of high quality water. Such regions are critically important for providing water supplies that serve a variety of purposes and uses. The value of water draining these lands is arguably higher now than when the National Wilderness Preservation System was created 50 years ago. The purpose of this technical report is to review currently available information and to encourage future research. The report discusses several important topics and themes relating to fresh water resources originating in wilderness areas, including: surface water quality and quantity; groundwater resources; water uses and benefits; ecosystem services and water valuation mechanisms; potential climate change impacts; water-related legislation; and case studies and maps. Case studies highlight the societal benefits that may be obtained from water derived from designated wilderness areas. A GIS mapping analysis of several regions provides a qualitative view of the value of water draining wilderness areas by illustrating the physical proximity of high-quality resources to populous regions. Scientific research completed in the last several decades has provided a framework for understanding the contributions and benefits of large volumes of high-quality water from wilderness areas for a variety of uses. More recent analysis has begun to refine our understanding of these resources in the areas of water supply and quantity, water quality, climate change impacts, and ecosystem services. However, additional crucial research is needed to document and evaluate the benefits of such resources and their importance to ecological vitality, to economies, and to future generations.

Keywords: wilderness, water, surface water, ground water, water quality, water quantity, ecosystem services, water use, water values and benefits, water supply

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About the cover:

South Fork Flathead River, Bob Marshall Wilderness, Montana (photo by Adam Johnson).

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Table of Contents

Figures

Tables

Introduction

Abundant clean water is essential for ecosystem processes and for the maintenance of human populations. However, the world's fresh water (ground water, surface water, and atmospheric moisture) accounts for less than 3 percent of the world's water volume, and less than 1 percent of that water is available for human use (WBCSD 2006). Renewable sources of fresh water may remain within natural systems, as in-stream flow or groundwater stored in aquifers, or the resources may be withdrawn for various beneficial uses.

Numerous anthropogenic and natural processes impact water resources. Watershed degradation and associated water quality impairments present serious risks to human health and quality of life. In fact, water quality impairments have been associated with the prevalence of disease (Toch 2000). Multiple processes also diminish the quantity of water available for use. The value of abundant supplies of high-quality water will therefore increase as threats to water resources expand and demands increase (Foti et al. 2010).

In the United States, public lands often contain watersheds that have been minimally modified by anthropogenic disturbances. Land use within units of the National Forest system, for example, is often minimal relative to agricultural or urban areas. Gifford Pinchot, the first Chief of the U.S. Forest Service (USFS), explained that one of the purposes for establishing the first national forests was to use them "as great sponges to give out steady flows of water for use in the fertile valleys below" (Pinchot 1907). According to the 1897 congressional act creating the National Forest System, the purposes of reserving forests were, among others, to protect and enhance water supplies and to secure favorable conditions of water flows (USFS 2000). Over 60 million people are served by public water supply systems located in watersheds containing National Forest System (NFS) lands (USFS n.d.).

Former USFS Chief Mike Dombeck (2003) argued that allowing forests to produce high quality water should remain "the highest priority of forest management." Recognizing the hydrologic alterations and water supply problems that may be associated with changes in climate, former USFS Chief Gail Kimbell indicated that the agency can "make a difference by managing national forests and grasslands to restore ecological processes and functions that support clean and healthy streams, lakes, and aquifers" (USFS 2009).

Purpose

Crucial research is needed to document and evaluate the benefits of wilderness water resources and their importance to future generations. Wilderness managers, national non-governmental organizations, local non-profit groups, and businesses recognize the critical importance of minimally altered forests, grasslands, and other wild areas in providing water supplies for a variety of uses. However, these groups may lack sufficient information about the quantity and quality of water draining from the nation's wilderness lands and similarly managed areas (Johnson 2003). The purpose of this technical report is to review currently available information and to encourage future research.

Some wilderness managers have noted the lack of specific quantitative information regarding the economic benefits from water originating on and draining from wilderness lands. Most agency literature and non-profit publications provide only qualitative evaluations. Few studies have employed data collection or hydrological modeling activities that resulted in estimates of flow or economic benefits from wilderness water (for example, see Brown and Froemke 2009). Several problems contribute to the lack of water quality/quantity research in wilderness areas; quantification of water needs is a challenging task.

To help fill the data gaps discussed above, and to promote additional research, this report discusses several important topics and themes relating to freshwater originating in wilderness areas:

- A brief discussion of the National Wilderness Preservation System
- Water quality and quantity
- Groundwater resources
- Water uses, benefits, ecosystems services, and valuation mechanisms
- Potential climate change impacts on wilderness water resources
- Wilderness water case studies, and
- Wilderness legislation and special provisions.

The reader should note that wilderness areas may influence water resources that cross through, but do not originate within their borders. For example, the Linville River passes through the Linville Gorge (Figure 1) in North Carolina, and the Salmon River flows through the Frank Church River of No Return Wilderness (Figure 2) in Idaho. Although this situation should be considered in evaluations of wilderness water, in this paper we focus on headwater drainages in which the sources of flow originate in wilderness areas.

Figure 1. Linville River, Linville Gorge, North Carolina (photo by Deborah Caffin; source, wilderness.net).

Figure 2. Frank Church River of No Return Wilderness, Idaho (photo by Tom Montoya; source, wilderness.net).

Wilderness Lands

The U.S. Congress created the National Wilderness Preservation System (NWPS) with the passage of the Wilderness Act of 1964 (Public Law 88-577; http://www.wilderness.net/NWPS/legisAct). The legislation listed the principal purposes of wilderness areas (recreational, scenic, scientific, educational, conservation, and historical uses) and stated that such areas may contain "ecological, geological, or other features of scientific, educational, scenic, or historical value." Water conservation and management for in-stream flows, ecological function, scientific values, maintenance of natural conditions, scenic benefits, and recreational opportunities is consistent with the Wilderness Act.

Wilderness within the NWPS is the most protected of all land categories in the United States and is managed by four Federal agencies. The U.S. Forest Service, the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), and the National Park Service (NPS), collectively protect more than 750 geographic areas (approximately 110 million acres) across 44 states. In addition, significant acreages have been proposed for wilderness designation and/or meet the well-known definition of wilderness as specified by the Wilderness Act:

> …an area where the earth and its community of life are untrammeled by man… without permanent improvements or human habitation… with the imprint of man's work substantially unnoticeable…. (http://www.wilderness.net/NWPS/legisAct#2).

Nevertheless, the law also allowed for water resource prospecting and the establishment of reservoirs and water conservation works in certain cases. These allowances appear to recognize the potential future benefits to human populations provided by the substantial water resources present in wilderness areas. The year 2014 marks the 50th Anniversary of the Wilderness Act, and the benefits of abundant high-quality water are arguably even more important 5 decades later as demand has increased (Foti et al. 2010).

Wilderness and similarly managed areas provide abundant clean water to many people (Spildie 2003). For example, many of the areas are within the headwaters of major drainages that provide water to downstream metropolitan areas. Generally, wilderness water is of higher quality than drainage from urban and agricultural lands (USFS 2002), in part because the sources are situated in the basin headwaters. According to Irland (1979), "…protecting wildlands is a prime means of protecting water quality. High quality water for agriculture, municipal and industrial uses and fish and wildlife habitat is one of the most important services of wildland environments." In addition to providing surface water flows, wilderness areas often contain large intact watersheds that recharge aquifer systems.

Wilderness Water Quality

Regions of minimal human development (such as some forests and scrublands) are often sources of high-quality runoff (Brown and Binkley 1994), and the importance of such water will increase as development proceeds. In general, the same can be said of wilderness areas, which typically provide the highest quality water. Surveys by Hass et al. (1986) and Cordell et al. (2008) indicate that, of the many reasons for the high valuation of wilderness by citizens, protection of water quality consistently receives the highest ranking.

Human activities, development, and pollution sources that degrade water quality are largely restricted to non-wilderness lands. Active and abandoned mines, oil and gas development, fish facilities, industries, and hazardous waste sites provide point sources of pollution. Many of the approximately 38,000 abandoned mines and hazardous waste sites on national forests cause significant pollution (USFS 2000). Common water contaminants include metals, petroleum hydrocarbons, pesticides, salts, nutrients, industrial compounds, wastewater treatment plant effluents, salinity, and suspended sediment. Changes to various water quality parameters such as clarity, salinity, dissolved oxygen, temperature, and suspended sediment may affect downstream uses and benefits (Dissmeyer 2000). The high quality of hydrologic resources in headwater areas can in many cases be attributed to the general lack of such activities within wilderness boundaries.

Fire management impacts to water quality may include increased sediment, turbidity, temperature, and nutrient concentrations (Dissmeyer 2000). Active timber management can increase sediment transport, water temperatures, and nutrient concentrations due to harvesting and fertilizer application (Cole and Landres 1996). Sediment from logging and roads can clog pipes and pumps, and cause channel changes, landslides, floods, and debris flows. Corridors such as roads, trails, utilities, railroads, and airfields may alter ground water and surface water hydrology by increasing the magnitude and frequency of peak flows and increasing total runoff and peak runoff rate (USFS 2000). Corridors can also cause an increase in erosion and sedimentation and introduce contaminants such as metals, hydrocarbons, pesticides, salts, and nutrients.

Concentrated and dispersed recreation may impact water quality through increased sediment transport and human and animal wastes (Perry and Swackhammer 1990). Other potential anthropogenic water quality problems include agricultural runoff, livestock grazing, fertilizer application, aquatic invasive species, and urbanization (wastewater, urban storm runoff, underground storage tanks, abandoned wells, and landfills). Hydromodifications—dams, headgates, reservoirs, canals, water wells, diversion ditches, and flumes—can affect physical, chemical, and biological water quality through cross contamination of water bodies, loss of habitat, temperature changes, variations in sediment transport, eutrophication, and alterations in flow regimes and dissolved oxygen concentrations (Dissmeyer 2000). Natural sources of water quality degradation include wildlife, birds, aquatic organisms, wildfire, and microbiological contamination such as giardia, cryptosporidium, naegleria, and coliforms, which may also have anthropogenic sources (Perry and Swackhammer 1990).

Water temperature affects chemical interactions and biological activity, and can be influenced by overstory removal, revegetation, and stream reconfiguration activities. The Clean Water Act mandates that certain water temperature parameters must be maintained. Some reservoirs, for example, must be retrofitted to reduce the temperature of effluent water. The necessity of expenditures may be tied to the temperature of headwater streams, but also may be due to the nature and construction of reservoirs. Temperature and nutrient increases can aggravate problems with algae in the form of nuisance and/or toxic algal blooms, and in some cases, recreation has been suspended until a solution is found. Wilderness water is generally cold, which reduces problems with eutrophication.

Salinity affects almost all water uses by reducing crop yields and damaging appliances and industrial machinery. Water clarity affects aesthetic values and the depth of light penetration, which can affect habitat structure. Wilderness water may be naturally high in dissolved organic carbon (DOC), which will not cause problems for irrigation, but must be removed or treated prior to consumption.

Economic values for water quality changes for various uses can be determined using several estimation methods, as discussed below (e.g., Koteen et al. 2002). Physical barriers (such as dams) or chemical treatments (such as chlorine) may be viewed as necessary interventions. Alternatively, watershed management can deal with resource uses that threaten to impair water quality, and may be more cost-effective than treatment solutions (Toch 2000).

The general high quality of wilderness water can be attributed to the lack of the activities, development, and pollution sources identified above. However, we have not identified any studies that explicitly compared water quality data from within and outside of designated wilderness lands or similarly managed areas. According to Pringle (2001), "there is little information in the U.S. about the contribution of wilderness.... to the protection of water quality, either within wilderness or for off-site benefits." One recent study, however, provided some limited wilderness water quality information that is useful for comparison purposes. Baseline physical and chemical data were collected at 22 streams within and adjacent to the Cloud Peak Wilderness (Figure 3) in the Bighorn Mountains of north-central Wyoming (Ferguson 2007; Wilderness Watch 2009; Table 1). Snow and precipitation accumulated in the wilderness represent an important water resource for municipalities, wildlife, recreation, agriculture, and industry in Wyoming. Table 1 also provides data for several non-wilderness streams located within or relatively close to the Bighorn Mountains in Johnson, Bighorn, Sheridan, and Washakie Counties (USGS 2012). In addition to draining the Cloud Peak Wilderness, the non-wilderness surface water features receive flow from areas whose land uses/land cover types include forests, rangelands, and other mixed uses.

Figure 3. Cloud Peak Wilderness, Wyoming (photo by Todd Blythe; source, wilderness.net).

Water quality in the Cloud Peak Wilderness reflects soil types, the local geologic setting (glaciated granitic terrains of the Bighorn Mountains), and the lack of human-influenced land uses. No point source discharges, reservoirs, logging, or motorized uses are present, and only limited seasonal livestock grazing is accommodated. Table 1 shows that, in general, water quality is better within this mountainous wilderness area than in the lower lying, more intensively used areas. For example, specific conductance and alkalinity values are generally lower in the wilderness streams studied. All of the high-elevation streams exhibited soft water in contrast to the Tongue and Bighorn Rivers, which were moderately hard to very hard, respectively. Wilderness streams also had lower sulfate concentrations. The wilderness streams exhibited low chloride, phosphate, and total suspended sediment concentrations and low turbidity levels. However, since analytical reporting limits varied between studies, comparisons between wilderness and non-wilderness data are difficult in some cases.

Table 1. Water quality in wilderness and non-wilderness streams, north-central Wyoming.

Stream Name	LU	Temp (°C)	pH (S.U.)	SpC (µS/cm)	DO (mg/L)	Alk (mg/L)	H (mg/L)	SO_4 (mg/L)	Cl (mg/L)	N (mg/L)	P (mg/L)	Turb (NTU)	TSS (mg/L)
E. Fork Big Goose Creek	Wilderness	15.5	7.6	70	7.3	8	8.4	1.2	<1.0	0.01	<0.05	0.2	<5
Buckley Creek		11.8	7.9	23	6.6	10	6.0	1.0	<1.0	0.05	<0.05	0.1	<5
Clear Creek, Middle Fork		12.3	7.7	47	7.9	5	7.7	1.2	<1.0	0.04	<0.05	0.8	<5
Clear Creek, North Fork		7.7	8.0	30	9.1	9	10.2	1.4	<1.0	0.20	<0.05	0.5	<5
Clear Creek, South Fork		14.9	8.1	90	7.6	11	9.4	1.1	<1.0	0.02	<0.05	0.8	<5
Coney Creek		16.7	7.7	28	7.1	6	7.5	1.2	<1.0	0.01	<0.05	0.9	<5
Cross Creek		11.1	8.2	36	7.5	10	7.5	1.4	<1.0	0.09	<0.05	---	<5
Elk Creek		12.4	8.1	25	6.4	11	9.0	1.0	<1.0	0.08	<0.05	1.7	<5
E. Fork Little Goose Creek		12.0	8.0	20	7.4	8	5.0	1.0	<1.0	0.01	<0.05	0.5	<5
Medicine Lodge Creek		16.4	7.9	30	7.6	8	4.0	1.0	<1.0	0.05	<0.05	0.2	<5
Oliver Creek		13.2	7.9	58	6.7	7	1.0	1.2	<1.0	0.01	<0.05	---	<5
Paintrock Creek		9.8	7.6	---	7.2	6	5.0	1.0	<1.0	2.08	<0.05	0.2	<5
Paintrock Creek, Middle		13.2	7.8	32	8.0	12	11.0	2.0	<1.0	0.05	<0.05	0.1	<5
Paintrock Creek, North		10.2	7.6	20	8.7	8	7.0	2.0	<1.0	0.07	<0.05	0.2	<5
Piney Creek, South		13.0	8.3	18	6.8	9	8.0	1.0	<1.0	0.08	<0.05	0.7	<5
Rock Creek, South		14.2	8.4	26	7.8	13	9.0	1.0	<1.0	0.05	<0.05	0.3	<5
Shell Creek		15.9	---	42	7.5	10	6.0	1.0	<1.0	0.05	<0.05	0.3	<5
Tensleep Creek, East		9.0	7.6	60	8.3	8	6.8	1.0	<1.0	0.04	<0.05	0.3	<5
Tensleep Creek, Middle		12.9	8.2	70	5.2	6	5.7	1.1	<1.0	0.04	<0.05	0.3	<5
Tensleep Creek, West		17.9	7.9	200	7.1	7	7.4	1.1	<1.0	0.02	<0.05	0.5	<5
Wilderness Creek		13.9	8.3	130	6.8	12	6.5	1.1	<1.0	0.04	<0.05	---	<5
Willett Creek		14.7	8.0	28	---	11	10.0	1.0	<1.0	0.34	<0.05	1.5	<5
Sage Crk. nr Lovell	M	20.0	8.1	1130	8.0	---	---	---	---	---	---	---	---
Shoshone R. nr Kane	M	14.5	8.2	878	9.0	---	---	244.0	---	---	---	---	---
Bighorn R. at Kane	M	11.7	8.1	826	10.4	167	265.0	248.0	13.3	0.40	0.50	135.0	1.3
Salt Crk. nr Sussex	M	22.0	7.9	2010	6.7	---	---	---	---	---	---	---	---
Crazy Woman Crk. nr Arvada	R	15.7	---	1800	7.5	---	---	---	---	---	---	---	---
Salt Crk. nr Sussex	M	---	---	---	---	---	---	---	---	---	---	---	---
Goose Crk. nr Acme	M	16.5	8.4	616	10.3	126	---	---	---	---	---	18.5	---
Tongue R. nr Dayton	F	6.3	7.8	223	11.1	114	115.0	4.1	0.7	0.10	0.02	1.7	0.4
Powder R. nr Arvada	M	---	---	---	---	---	---	---	---	---	---	---	---
Cottonwood Crk. nr Winchester	M	---	---	---	---	---	---	---	---	---	---	---	---
Middle Fk. Powder R. nr Barnum	---	18.6	7.9	106	7.5	---	---	1.9	0.3	0.04	0.08	---	---

	Temp (°C)	pH (S.U.)	SpC (mS/cm)	DO (mg/L)	Alk (mg/L)	H (mg/L)	SO_4 (mg/L)	Cl (mg/L)	N (mg/L)	P (mg/L)	Turb (NTU)	TSS (mg/L)
Summary Statistics (Wilderness Streams)												
Minimum	7.7	7.6	18	5.2	5	1.0	1.0	<1.0	0.01	<0.05	0.1	<5
Maximum	17.9	8.4	200	9.1	13	11.0	2.0	<1.0	2.08	<0.05	1.7	<5
Mean	13.1	7.9	52	7.3	9	7.2	1.2	<1.0	0.16	<0.05	0.5	<5
Summary Statistics (Non-Wilderness Streams)												
Minimum	6.3	7.8	106	6.7	114	115.0	1.9	0.3	0.04	0.02	1.7	0.4
Maximum	22.0	8.4	2010	11.1	167	265.0	248.0	13.3	0.40	0.50	135.0	1.3
Mean	15.7	8.1	949	8.8	136	190.0	124.5	4.8	0.18	0.20	51.7	0.8

--- = No data available
S.U. = standard units; SpC = Specific Conductance
DO = dissolved oxygen; Alk = Alkalinity
Turb = Turbidity; NTU = nephelometric turb units
M = Mixed; R = Rangeland; F = Forest

N = Nitrate + Nitrite; SO_4 = Sulfate; Cl = Chloride
TSS = Total Suspended Sediment
P = Phosphorus; H = Hardness as CaCO3
LU = Land Use; nr = near

Values for wilderness streams are generally associated with a single measurement.
Values for non-wilderness streams are means for each site, which are based on one or more measurements.

Sources:

U.S. Geological Survey, 2001, National Water Information System (NWISWeb) [Surface Water / Bed Sediment]: U.S. Geological Survey database, accessed August 11, 2012, at http://water.usgs.gov/nawqa/data

Cloud Peak Chapter Wilderness Watch (2009)

Wilderness Water Quantity

As illustrated above, wilderness areas typically provide high-quality water for in-situ and extractive uses. In many regions of the United States, such lands also provide disproportionately high volumes of water relative to non-wilderness land uses (Brown and Froemke 2009). These resources support ecological functions and are also commodities for downstream users such as irrigators, utilities, industries, and municipalities. The protection of human water supplies is one important benefit of setting aside wilderness lands.

Altered water flow rates and volumes may affect numerous economic activities (Gray and Young 1984). Many of the beneficiaries, however, don't directly pay for the water. In fact, water is not typically priced in the market (Peterson and Randall 1984), and payments at the time of use and in proportion to use are small or nonexistent (Clawson 1978). Useful quantities are substantial, especially where wilderness areas are located near urban centers (Brown and Froemke 2009; Spildie 2011). Until recently, estimates of nationwide wilderness water quantity data were lacking, and rigorous studies of the amount of runoff draining individual wilderness areas in the United States have yet to be completed.

The amount of water available affects both in-situ and extractive uses. Changes in water quantity often affect the benefits received by users (Koteen et al. 2002). However, until recently few attempts have been made to estimate wilderness contributions to water supplies across the nation. U.S. Geological Survey stream gages and snowpack telemetry sites within or near wilderness areas may be useful for additional research.

Fresh water generally originates as precipitation and then either returns to the atmosphere through evapotranspiration, infiltrates to aquifers as groundwater, or flows overland to oceans through stream flow. Brown et al. (2008) estimated water supply volumes for explicit areas within the 48 states excluding Alaska and Hawaii. Water supply was calculated as precipitation minus evapotranspiration. The remainder of flow in the hydrologic system was assumed to be surface water or groundwater. The study also assumed that mean annual changes in surface and groundwater storage (e.g., groundwater pumping, surface water diversions, imports to the basin, or groundwater flow out of basins) are negligible. Water supply was calculated using several hydrologic models that were calibrated using estimates of precipitation and runoff at 655 monitoring stations across the 48 states.

Study results indicate that approximately one-fourth of the available water supply (two-thirds in the 11 western contiguous states) originates on Federal lands under the control of the USFS, BLM, NPS, FWS or Bureau of Indian Affairs (BIA). More than half of the water supply for the 48 contiguous states originates on forested land, which covers only 29 percent of the surface area of the 48 contiguous states. Thirteen states receive more than 70 percent of their water supplies from Federal lands. The total water supply in the coterminous

United States was estimated to be 1,768 km^3/yr (424 mi^3), of which 429 km^3/yr (103 mi^3) originates on Federal land. As of September 2004, 117.8 km^2 (45,500 mi^2) of the NFS was designated as wilderness (Brown et al. 2005). Using that estimate, the volume of water supply originating on NFS wilderness areas was estimated to be 66 km^3/year (16 mi^3/year) or about 25 percent of the total supply from NFS lands.

Alaska and Hawaii were excluded from the Brown et al. 2005 study due to a lack of sufficient data. According to The Wilderness Institute et al. (2012), Alaska has 48 designated wilderness areas totaling almost 58 million acres, which is 52 percent of the state's land area and more than half of all wilderness land in the United States. Hawaii has two wilderness areas with more than 155,000 acres of wilderness land. Clearly, these two states together provide significant water volumes from wilderness areas.

Brown and Froemke (2009) refined the data from Brown et al. (2008) to arrive at estimates of water supply volumes contributed by designated wilderness areas in the coterminous United States for the period from 1953-1994. Water volumes were based on wilderness land acreages and water supply depths of contribution. Calculations assumed that water entering the soil that is not lost to evapotranspiration is pumped to the surface or eventually returns to the surface at some point downstream and is available for use.

The study found that almost 5 percent of the total U.S. water supply originates in designated wilderness areas in a typical year, although these areas represent only 2.5 percent of the land area. The estimated average annual depth of supply (water supply volume per land area) in the coterminous United States is approximately 230 mm/year (9.1 in/year), and the wilderness depth is almost double that amount (approximately 450 mm/year or 17.7 in/year). In USFS Region 6, the average depth of supply in wilderness areas is 1,450 mm/year (57.1 in/year) (Brown and Froemke 2009).

Because the calculations provided by Brown and Froemke (2009) were based on data from weather stations, and such instrumentation is often lacking in wilderness areas, the results are based in part on spatial interpolation between weather stations, which introduces calculation errors. Nevertheless, these estimates are useful as a starting point for understanding the value that wilderness areas provide in terms of water quantity. Unfortunately, these estimates of water supplies (volume per land area) provided by wilderness areas could not be independently verified due to the lack of appropriately located stream gages. Future research could include the installation and monitoring of gages, and possibly snowpack telemetry instrumentation, in one or more strategically located wilderness areas to allow for evaluation of the existing water quantity estimates.

The total estimated mean annual water yield from designated wilderness areas is approximately 86.5 km^3/year (21 mi^3) (Brown and Froemke 2009). Figure 4 provides a graphical summary of wilderness area contributions to U.S. water supplies.

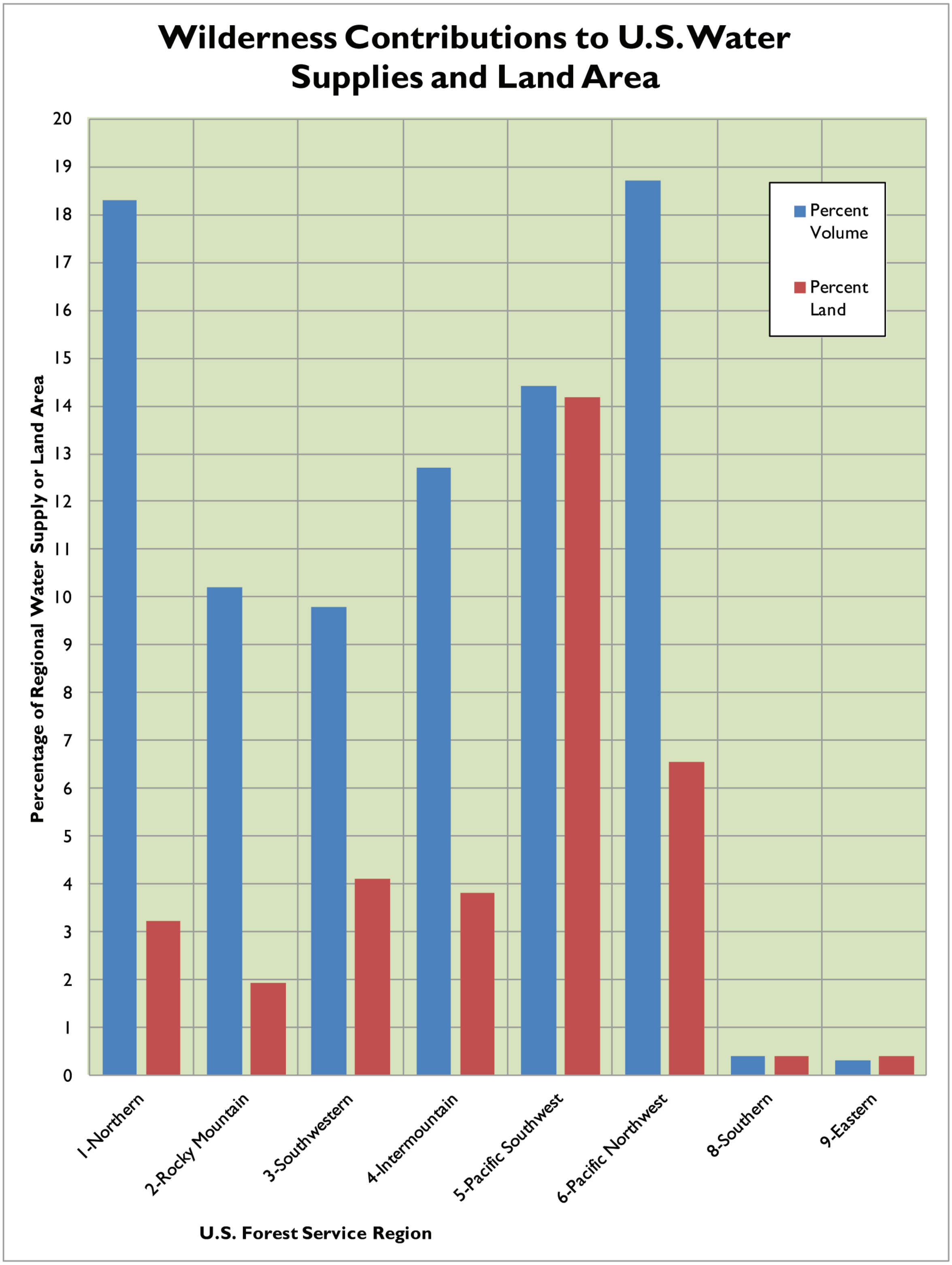

Figure 4. Wilderness contributions to U.S. water supplies and land area (modified from Brown and Froemke 2009).

In USFS Regions 1 through 6, such designated areas provide at least 9 percent of the water in each region. In the Pacific Northwest and Northern regions (Oregon, Washington, northern Idaho, Montana, and North Dakota), more than 18 percent of the water volume is provided by wilderness lands. In most cases, the percent of water supply provided as a function of the entire regional water supply far outweighs the percentage of land area under wilderness designation. As shown in Figure 5, the depth of water supply contribution (in mm/yr) is often higher in wilderness areas, especially in the western United States. Water volumes from wilderness areas in Alaska and Hawaii have yet to be quantified.

Estimates of water volumes derived from wilderness areas can be used for a variety of purposes and applications. For example, wilderness managers can employ these values to help make decisions regarding individual wilderness areas or groups of wilderness lands within different regions of the country. With a better understanding of the amount of clean water that flows from relatively undisturbed ecosystems in wilderness areas, the public may be more likely to support the proposed conservation of additional lands that produce high-quality water but that are not currently protected as wilderness.

Groundwater

As discussed above, quantitative wilderness water quality and quantity information is limited. Available studies focus almost exclusively on surface water, with little to no groundwater data or investigations identified in the literature. Many forests serve as recharge areas for aquifers that supply water for municipal, irrigation, and other needs (USFS 2000). Under the Organic Act, the USFS, which manages most wilderness areas, has the authority to manage water, including ground water, under both Federal and state laws. However, the agency has historically assumed a limited role in groundwater management on NFS lands (Glasser 2007).

According to USFS proposed policy, groundwater should be managed to ensure sustainability and long-term resource protection, and assessment and quantification of the resource and groundwater uses are integral components of the management strategy (Glasser 2007). However, limited research has been completed to date on the magnitude and quality of USFS groundwater resources or their potential value.

Changes in climate over the next century are anticipated to reduce groundwater recharge on a global scale (Rice et. al. 2012), but the timing and magnitude of such reductions are not well understood. A recent ecosystem services project within the USFS (Weidner and Todd 2011) identified watersheds nationwide that are most important in terms of their links to drinking water sources. However, only surface water sources were considered in the analysis. Despite the well-known interconnections between groundwater and surface water, groundwater was excluded from the study due to a reported lack of national-scale data.

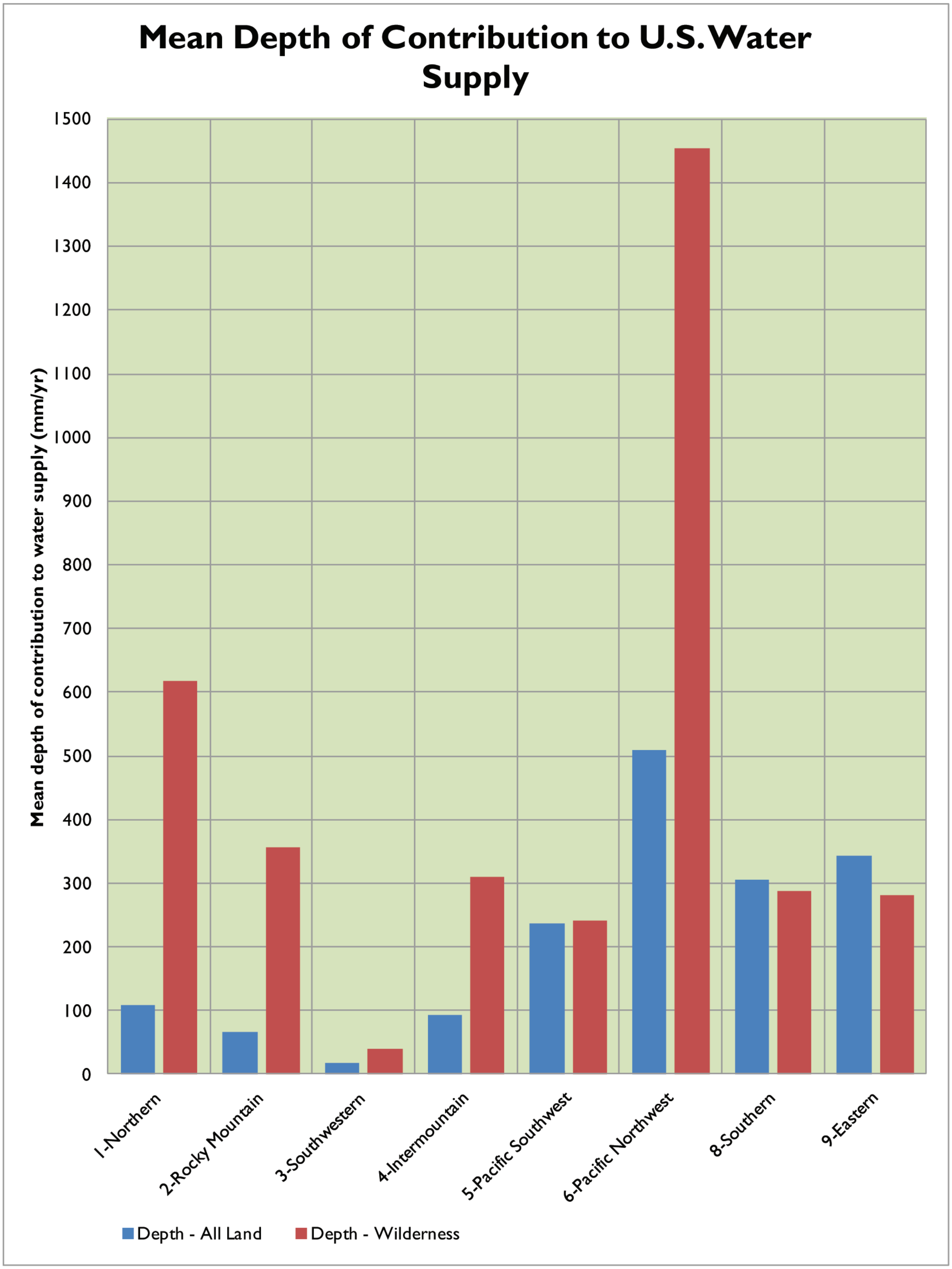

Figure 5. Mean depth of contribution to U.S. water supply area (modified from Brown and Froemke 2009).

Water Uses, Benefits, and Ecosystem Services

Water sustains all life on earth. Direct resource benefits to human populations include residential, municipal, commercial, industrial, mining, utilities, fisheries, commercial (crop) irrigation, household irrigation, and stock watering. In-situ benefits or values include recreation (boating, swimming, fishing, camping, and wildlife viewing), transportation, waste disposal and assimilation, hydropower, subsistence, species and biodiversity conservation, aquatic habitat, and ecosystem function. In addition, several non-use and/or intangible benefits are also recognized, including scenery, existence, bequest, therapeutic, and Indigenous cultural and spiritual values. Some of these societal benefits are shown in Figure 6. An exhaustive listing of the potential uses and benefits of water derived from wilderness areas is beyond the scope of this paper.

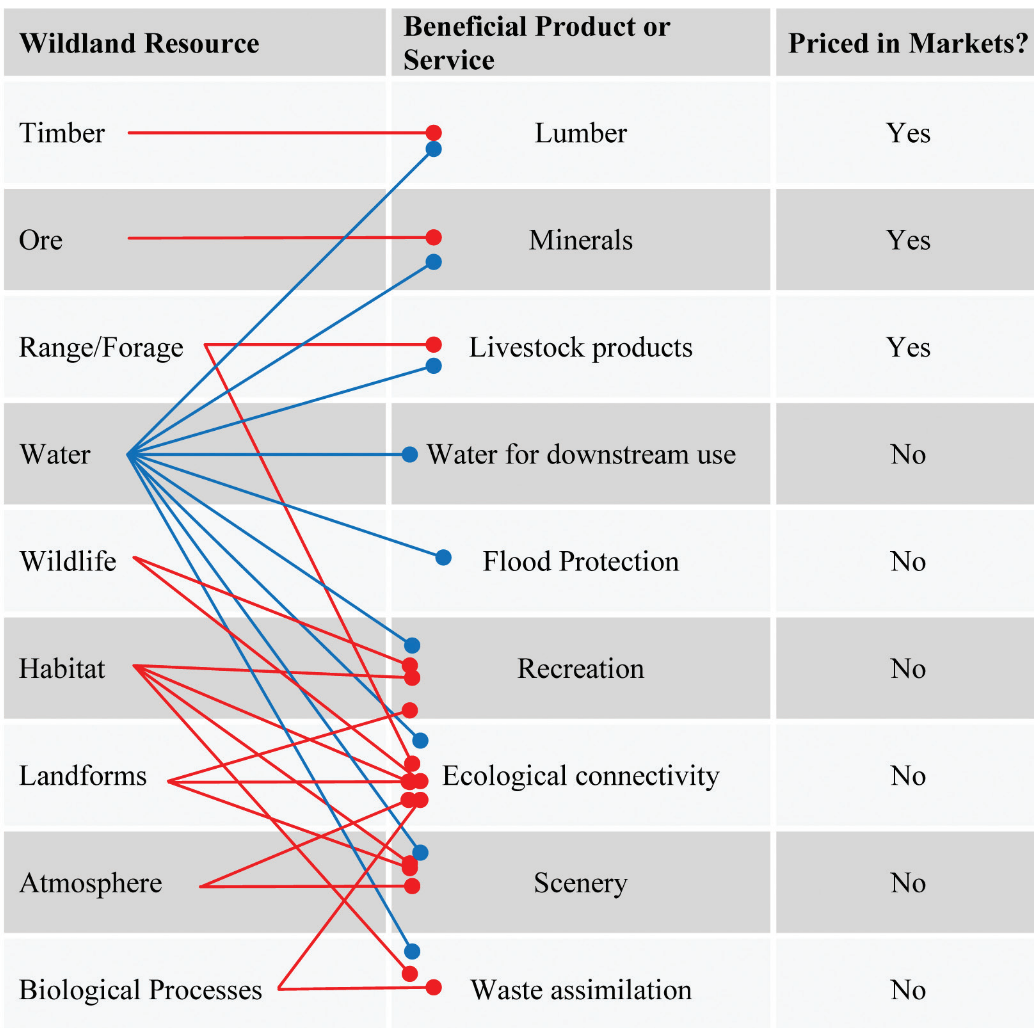

Figure 6. Wildland resources and benefits (modified from Gray and Young 1984).

Depending on the use, some of these benefits are significantly enhanced or degraded by changes in water quality and/or quantity, and the various uses require different water quality attributes (Koteen et al. 2002). For example, water quantity, salinity, clarity and Total Suspended Sediment (TSS) are important parameters for municipal use (residential, public, and commercial purposes). For agricultural use, salinity, TSS, water quantity, and temperature are important for both producers and consumers. Recreational use is varied, and these activities may be affected differently by multiple water quality parameters. Industrial processes use water as a production input for cooling, condensation, washing, and transport of materials. TSS, salinity, and water quantity are important parameters for industrial uses, and values measured are typically the costs of production and benefits to consumers. Water quantity and salinity are important parameters for hydropower use (Koteen et al. 2002).

Nonmarket water benefits include onsite use and nonuse (scenery, existence, bequest, spiritual, therapeutic, and cultural) values; in these cases, all water quality parameters may be important. Other benefits that are difficult to price in markets include transportation, waste disposal and assimilation, subsistence, ecological continuity, and aquatic habitat, each of which have different water quality requirements (Jackson et al. 2001; Koteen et al. 2002; Williams et al. 1990).

Armatas (2012) identified more than 30 ecosystem services that provide water-related benefits to a variety of stakeholders within and near the Shoshone National Forest of Wyoming´s Bighorn Basin. The research identified four stakeholder perspectives/viewpoints: environmental, agricultural, Native American, and recreation. The *water quality* ecosystem service was determined to be the most important benefit to two of the four viewpoints, and was highly important to three of the four perspectives. These results are consistent with earlier surveys by Hass et al. (1986) and Cordell et al. (2008) which indicated that protection of water quality consistently receives a high ranking by the public. *Household and municipal use* of water was most important to two of the viewpoints, and was important to all four perspectives.

The USFS has protected 1.4 million acres of wilderness in five designated areas within the Shoshone National Forest. The geographic extent of the study by Armatas (2012) includes both wilderness and non-wilderness lands, and the investigation was not specifically focused on wilderness areas. Nevertheless, the most important ecosystem service identified in the study (*water quality*) can be directly tied to the existence of large tracts of relatively pristine wilderness in Shoshone headwater areas. The high quality of water for *household and municipal use* (the other most important identified ecosystem service) can also be linked to wilderness lands within the forest. Other ecosystem services identified by Armatas (2012) that owe their utility in part to the existence of wilderness lands within the study area include recreation; preservation of livelihoods, lifestyles, and landscapes; Indigenous cultural and spiritual values; river-based fishing; conservation of species and biodiversity, and glacier-based ecosystem services.

Valuation

One definition of the benefit or value of a water resource is “the amount that a perfectly rational and well-informed user...would be willing to pay for it” (Gray and Young 1984). However, the physical characteristics of water, including its mobile, transient, and fluid nature, make market valuation of the resource difficult. The dimensions of quantity, quality, time, and location are important components of the valuation problem, and water may be used beneficially for multiple purposes at different locations and multiple times. Total value is considered to be a sum of the net positive benefits and negative consequences of water use (Gray and Young 1984), and the benefits of wilderness water extend beyond those that can be priced in markets.

Water quality modifications impact the benefits received, and some of these benefit changes can be quantified (Koteen et al. 2002). Varying numbers of parameters are necessary to define water quality depending on the intended use(s). Changes in water quality affect multiple uses differently, and both producers and consumers of water benefit or suffer from water quality changes. High quality water and temporal constancy of water quality parameters minimize costs associated with managing, purifying, and distributing water. Hydrologic contributions from wilderness often fulfill these requirements (e.g., USFS 2002). Wilderness ecological services include protection of watersheds and water quality (Loomis and Richardson 2001).

Placing an economic value on wildland water can be accomplished using several market and non-market techniques. Water for agricultural and industrial use, for example, is an input into production processes that ultimately yield final goods (Peterson and Randall 1984). Values can be more easily calculated for these water uses than for non-market uses. For example, economists can calculate the cost savings to municipal water treatment agencies and water users if the quality of the input is high. Pure source waters lower the cost of treatment in terms of settling basins, sediment precipitators, and filtration technology. New treatment facilities can cost over $50 million, with at least $3 million in annual operating costs (Loomis et al. 2000). The savings due to prevention of sediment transport ranged from $130,000 to $260,000 from one national forest. If generalized to wilderness acreage, the cost savings could range from $9 to $18 million (Loomis and Richardson 2001). Headwater drainages (where most wilderness areas are located) also generally exhibit low levels of dissolved solids and contaminants, and water resources generally need lower levels of treatment than water from lower in the watershed (Dissmeyer 2000).

The contingent valuation method involves asking people who benefit from watershed protection (clean water) what they would pay for that service (Loomis et al. 2000). Contingent valuation uses simulated markets to estimate values people place on water quality changes. The travel cost method, which measures actual recreation behavior in terms of transportation and travel time costs (Brown 1991), can be used to compare sites that have different water quality characteristics.

Hedonic pricing techniques have been used to estimate the effect of water quality changes on property values (Koteen et al. 2002).

A conservative estimate of the annual *marginal value* of water flowing from the national forests is $3.7 billion (USFS 2000). The *marginal value* for the consumer is the price for a good, while the *total value* is the benefit to society of producer and consumer surpluses (Koteen et al. 2002). For the Forest Service study, water flow was determined with a quantitative model that estimated runoff in each USFS region. Water values were derived from estimates used for off-stream purposes ($40 per acre-foot), instream flow in the west ($17), and recreation and hydropower in the east ($8). The number above is a conservative estimate because the average value is greater than the marginal value, and because dilution, navigation, moderation of downstream flooding, water quality, and non-use values were not considered. In addition, the current marginal value is likely higher as urban development continues and populations rise.

Brown (1991) discussed additional types of wilderness water benefits that are more difficult to quantify but nevertheless contribute to the overall value of the resource. These include:

- Preservation and existence values: for example, the willingness to pay for the knowledge that a certain level of stream flow is preserved in a given wilderness area. Both citizens who recreate on the river and those who may never visit the wilderness may hold this value.
- Bequest value: a willingness to pay for preserving in-stream flows for future generations.

Potential Effects of Climate Change on Wilderness Water Resources

Little quantitative information is available regarding the potential impacts of a changing climate on water resources in wilderness areas, although some studies have been completed for U.S. water resources in general. Rice et al. (2012) indicated that a temperature increase of between 2 and 4 ºF (1 to 2 ºC) was observed in the Rocky Mountains of the western United States during the 20th Century. During the same period, researchers documented declines in precipitation and reductions in snowpack volumes. Temperatures are expected to rise an additional 2 to 10 ºF (1.1 to 5.5 ºC) in the 21st Century. Potential future impacts on water quantity and quality, stream flow, glaciers, snow, and wetlands are described in Table 2. Although these anticipated changes to the hydrologic cycle are not exclusive to wilderness areas, many will have a disproportionate impact on wilderness due to their locations in high-elevation headwater drainages.

Table 2. Selected climate-related hydrologic conditions, trends, and potential water-related impacts in the Rocky Mountain West (modified from Rice et al. 2012).

Variable	20th Century trend	Anticipated 21st Century response	Potential impacts on ecosystem services
Surface water quantity	Decrease in annual flows in MT and WY since 1967	Increase in peak flows; decrease in summer flows and annual flows	Greater flood magnitudes; loss of habitat from reduced stream flow; reduction in flows for water supply; increased groundwater use
Surface water quality	Variable water quality conditions nationwide	Decreased flows could increase chemical loads and disturbances may increase sedimentation.	Reductions in quality; increases in temperature (reduction in habitat quality); increased algae and higher water treatment costs
Stream flow timing	More than 10 days earlier since 1967 in some areas	4 to 5 weeks earlier in some regions	Change in the timing of flows available for water storage and recreation
Glaciers	Ice mass reductions; temporary mitigation of stream flow reductions	Loss of glaciers with subsequent stream flow reductions and increases in stream temperatures	Reduced water supplies; reductions in summer stream flows; decreases in water quality (increases in sediment and temperature).
Snow	Declining snow volume; earlier annual snowmelt	Significant snowpack loss	Decreased volume for water supply; altered timing of water flows for storage
Wetlands	Wetlands lost and wetland areas reduced	Continued wetland losses due to reduced precipitation, earlier snowmelt, and increased evaporation	Reductions in groundwater recharge and groundwater elevations

Armatas (2012) discussed potential climate change vulnerabilities in the Bighorn Basin of Wyoming with respect to ecosystem services that support a variety of uses. Many stakeholders involved in the study recognized climate change as a possible threat to water-based ecosystem services within the Bighorn Basin.

Case Studies—Wilderness Water and Urban Areas

The following examples highlight the societal benefits that may be obtained from water derived from designated wilderness or similarly managed areas. Each case illustrates the real or potential economic value created by the proximity of high quality water to urban areas.

San Francisco, California, receives approximately 85 percent of its water from the Hetch-Hetchy Reservoir system, a series of watersheds originating in Yosemite National Park (SFPUC 2013). The San Francisco Water Department was originally ordered to build a $500 million filtration plant, which would have doubled residential and commercial water bills. However, California's first filtration exemption was granted based on the quality of the natural source, which is attributed to the fact that the majority of the watershed is under Federal protection and sustains limited human land use. Ecological functions (e.g., intact soils and indigenous vegetative cover) serve as natural purification devices.

In the 1990s, the U.S. Environmental Protection Agency (EPA) ordered New York City to build a filtration plant at a cost of $6 to $8 billion. Instead, the city was able to avoid construction of the costly facility and today is managing the Delaware/Catskill and Croton watersheds for water quality protection. Management actions include prevention of development and land acquisition within the catchments. The Catskill/Delaware watershed project, completed in 1964, worked well prior to land development but tourism and suburban expansion compromised water quality. In 1989, the EPA released the Surface Water Treatment Rule, which required filtration unless human activities in the watershed could be controlled. The EPA's rule gave financial value to the Catskills' natural water purification services (Daily and Ellison 2003; USFS 2002).

The Bull Run surface water source in Portland, Oregon, also meets criteria for avoiding filtration. To qualify for the exemption, a watershed control program is required, and the water must pass tests for coliform bacteria and turbidity. Although the Bull Run area was logged for several decades, no public entry or commercial activity is currently allowed. These restrictions, as well as the geologic and ecological characteristics of the watershed, contribute to the high quality of the resource. Although an attempt to find the economic value of protecting this watershed was unsuccessful (Robbins et al. 1991), building, maintaining, and operating a filtration plant would cost the city about $3 million per year.

Water developers have noted the great potential for development of the resource within and adjacent to wilderness areas ("water warehouses") because of both elevation (gravity drainage reduces costs and energy usage that would be required for pumping) and temperature (volumes lost to evaporation are smaller) (Williams et al. 1990). Under the terms of the legislation creating the Holy Cross Wilderness (Figure 7) in Colorado, Congress affirmed the water rights of two cities: Aurora and Colorado Springs. Water in high mountain streams was scheduled for diversion and delivery. After public controversy and court battles, the project was suspended. Some large municipalities such as Denver, Colorado, use full treatment but the quality of supplied water is consistent. Water flowing from wilderness areas is often not subject to major temporal water quality changes.

Figure 7. Holy Cross Wilderness, Colorado (photographer, unknown; source, wilderness.net).

Case Studies—GIS Mapping

A pilot project completed at the Aldo Leopold Wilderness Research Institute (Spildie 2003) leveraged Geographic Information System (GIS) data to illustrate the locations of several wilderness areas and their hydrographic connections with the Fresno, California urban area (Figure 8). This study provides a qualitative view of the value of water draining wilderness areas and illustrates the physical proximity of the high-quality resources to this populous region. Further research could be completed to quantify both the extent of the City of Fresno's wilderness water use for various purposes and the value of the resource. Subsequent mapping provides a qualitative understanding of the contribution of wilderness water to the cities of Denver, Sacramento, and Seattle (Figures 9-11). These maps illustrate the spatial relationship between urban areas and headwater streams originating in wilderness (Spildie 2003). Many other population centers also receive water from wilderness areas. Initial attempts at quantification could include, for example, a tabulation of the number of hydrologic unit codes that lie inside wilderness boundaries. Although little quantitative information is available regarding direct or indirect groundwater contributions from wilderness lands to high-population areas, such data could prove crucial for ensuring sound management of urban water sources in the future.

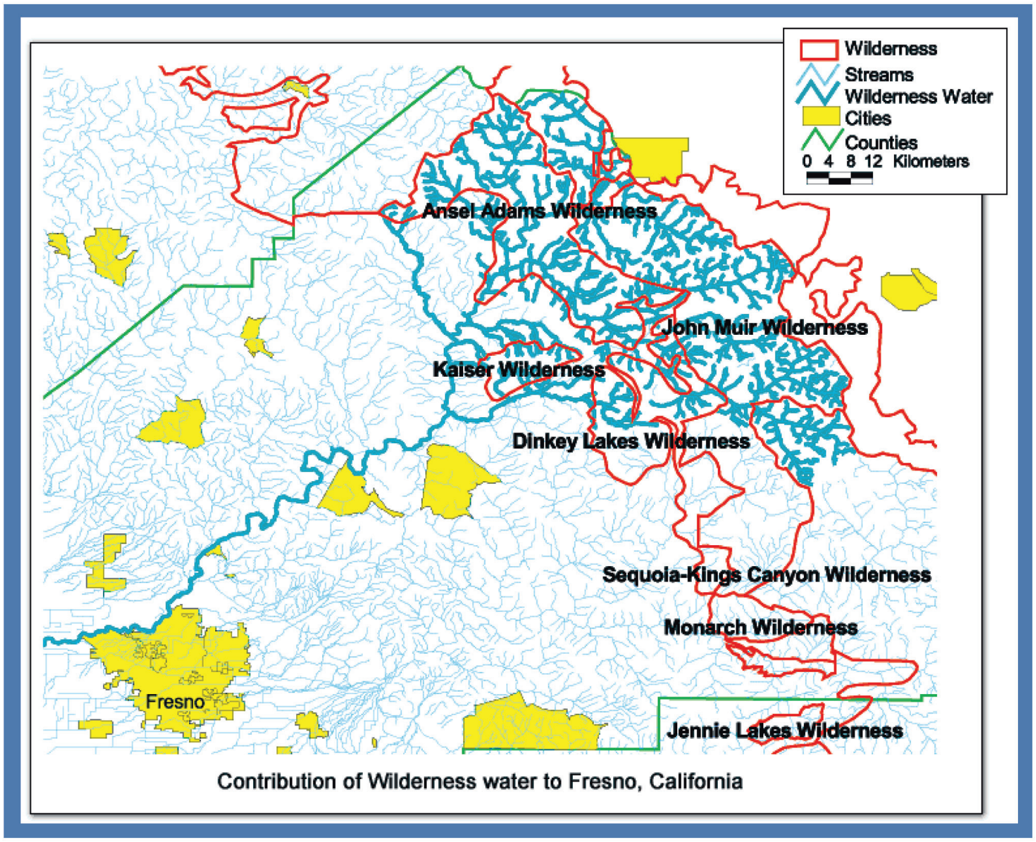

Figure 8. Fresno urban area rivers originating in wilderness (adapted from Spildie 2003).

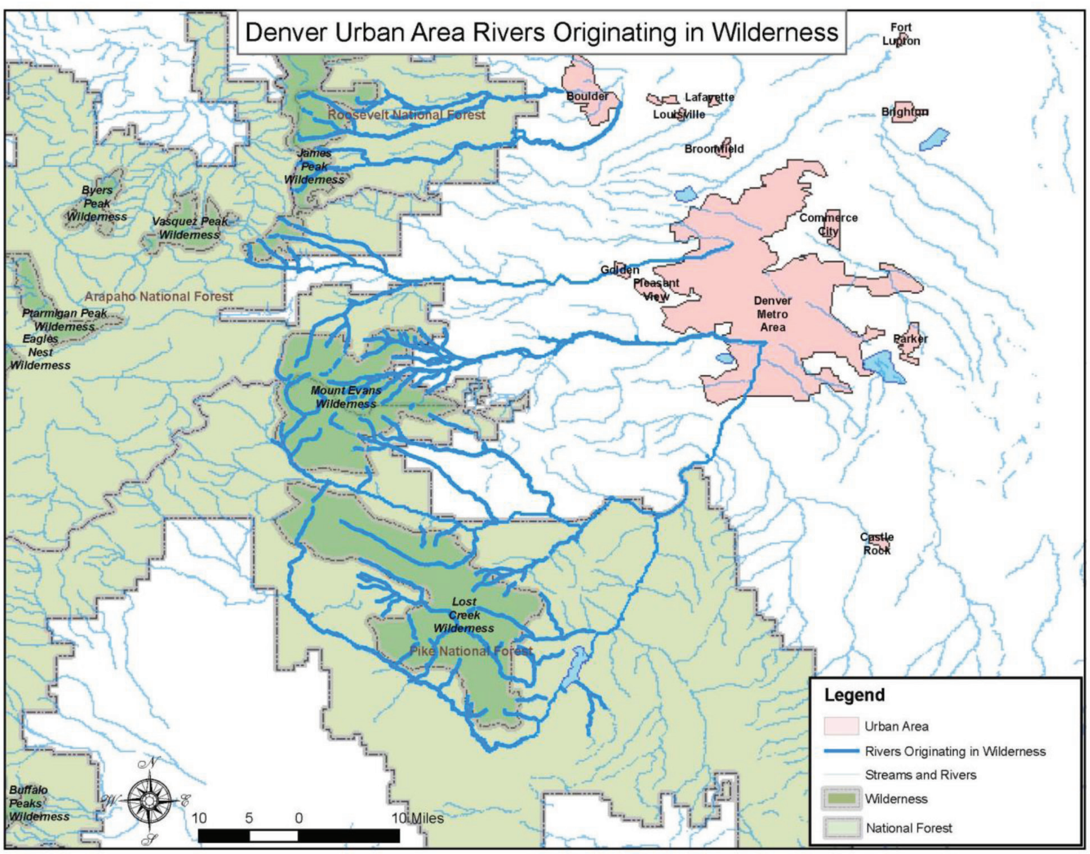

Figure 9. Denver urban area rivers originating in wilderness (adapted from Spildie 2003).

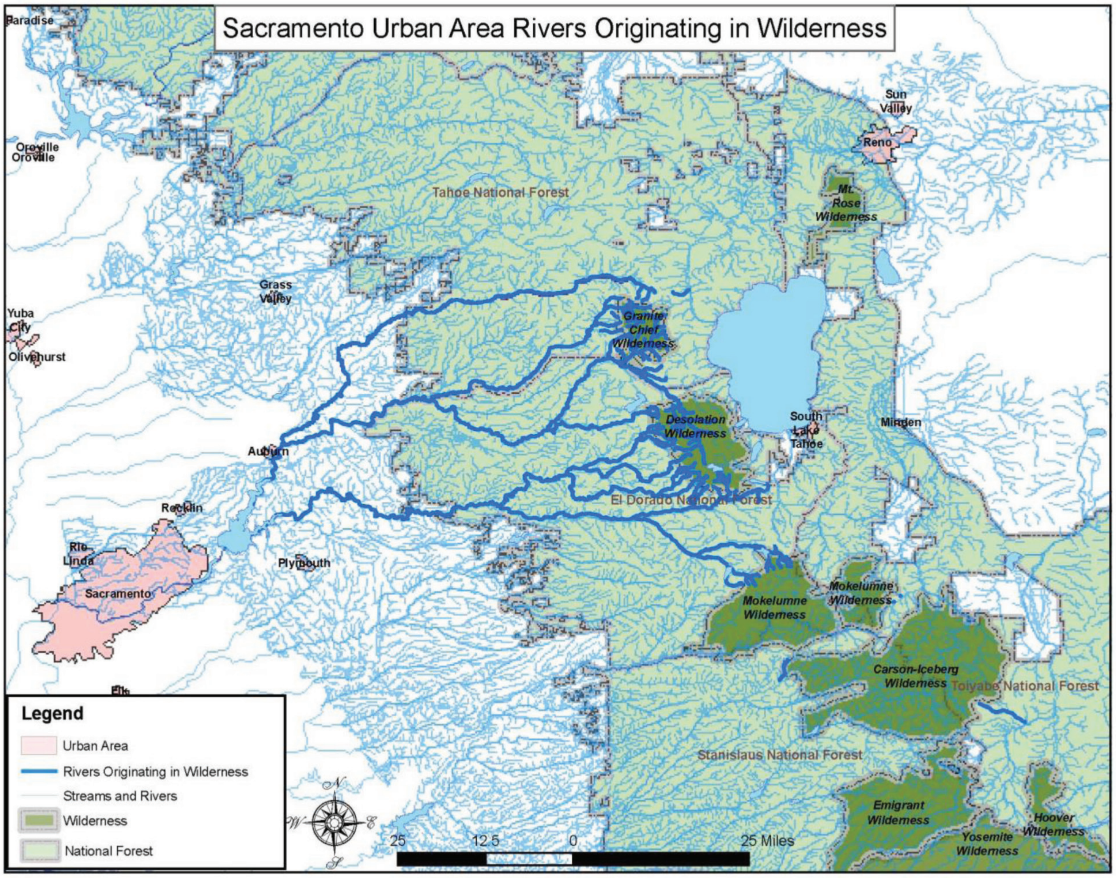

Figure 10. Sacramento urban area rivers originating in wilderness (adapted from Spildie 2003).

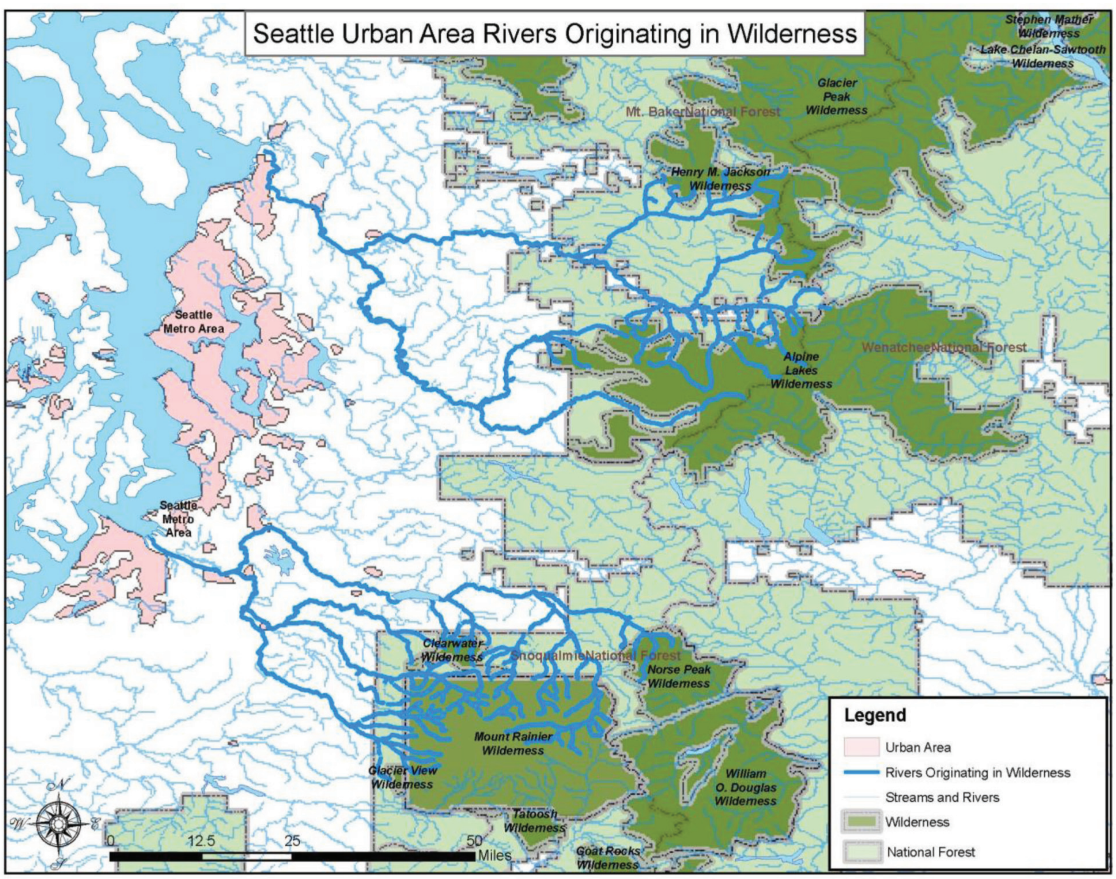

Figure 11. Seattle urban area rivers originating in wilderness (adapted from Spildie 2003).

Wilderness Legislation and Special Provisions

Although the 1964 Wilderness Act prohibited most forms of development within wilderness boundaries, subsequent legislation has recognized the human need for water resources that originate within those boundaries. For example, certain wilderness laws allow for the operation, maintenance, and repair of dams and other water impoundment facilities, and others provide for hydrologic monitoring for flood warning systems, flood control, and water reservoir operations. Snow pack telemetry equipment in some headwater areas provides information useful for the management of downstream hydroelectric projects. In some cases, hydrologic, meteorological, and/or climatological instrumentation (including snow sensors and stream gages) was deemed appropriate to further wilderness scientific, educational, and conservation purposes. These provisions, and area-specific provisions discussed below, implicitly recognize the value of wilderness water to society.

In addition, the use, operation, maintenance, repair, modification, or replacement of water resource facilities existing at the time of wilderness designation has generally been deemed acceptable. The term ''water resource facility'' typically includes irrigation and pumping facilities, reservoirs, water conservation works, aqueducts, canals, ditches, pipelines, wells, hydropower projects, transmission facilities, and other water diversion, storage, and transportation structures.

Some wilderness designation laws indicate that specific downstream uses of water that originates in wilderness areas are protected. For example, the Arizona Desert Wilderness Act of 1990 indicates that an existing water pipeline within the Mount Nutt Wilderness that serves the town of Oatman, Arizona can be operated, maintained, and upgraded. The Utah Wilderness Act of 1984 authorized sanitary facilities to ensure the health and safety of the communities serviced by the watersheds emanating from 10 wilderness areas. The Act also allows access for activities necessary to prevent watershed degradation.

The Colorado Wilderness Act of 1980, which created the Holy Cross Wilderness, ensured that the diversion and use of existing water rights for the Homestake Water Development Project by the cities of Aurora and Colorado Springs, Colorado, would not be altered by its passage. The legislation also allowed the construction, operation, maintenance and repair of the Homestake project. According to the Endangered American Wilderness Act of 1978, no rights to the diversion and use of the waters of Hunter Creek, the Fryingpan or Roaring Fork Rivers, or any tributaries of said creeks or rivers, by the Fryingpan-Arkansas Project were to be altered by the legislation. The Fryingpan-Arkansas project provides water to the Arkansas River Basin and the cities of Aurora and Colorado Springs through a series of diversion structures. The project is managed by the U.S. Bureau of Reclamation and the Southeastern Colorado Water Conservancy District. The current annual diversion volume is approximately 58,000 acre-feet.

The Endangered American Wilderness Act authorized the USFS to take appropriate actions to protect the California Santa Lucia and Ventana Wilderness watersheds (Figures 12, 13) and the health and safety of downstream communities. The USFS was also directed to "take whatever appropriate actions are necessary for …watershed protection…" Under the same law, sanitary facilities are to be used to ensure the continued health and safety of the communities served by the Lone Peak Wilderness (Figure 14) in Utah. Access is allowed for the purpose of guaranteeing the continued viability of existing watershed facilities to prevent the degradation of water quality in the Lone Peak area.

Figure 12. Santa Lucia Wilderness, California (photo by Brad Eells; source, wilderness.net).

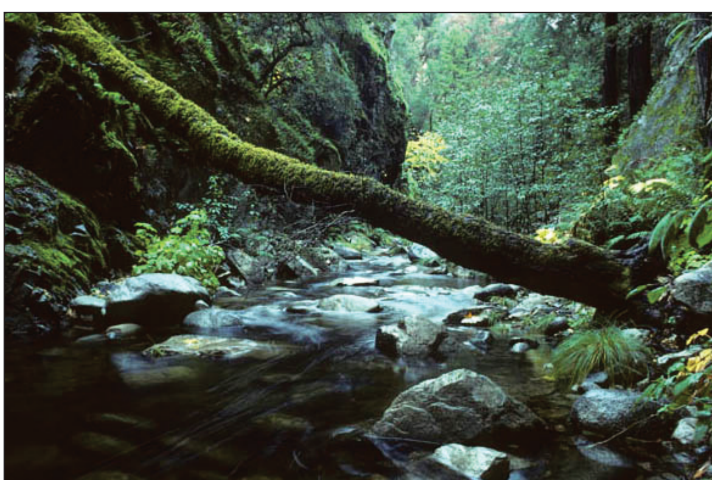

Figure 13. Ventana Wilderness, California (photo by George Wuerthner; source, wilderness.net).

Figure 14. Lone Peak Wilderness, Utah (photo by Steve Scheid).

Gorte (2011) provided a legislative summary of wilderness special provisions and prohibited/permitted uses within wilderness areas. Numerous statutes have allowed for operation and maintenance of existing water resources infrastructure (dams, canals, pipelines, and other improvements), and some laws have allowed for the construction of new water-related facilities, including hydroelectric generators and power projects, water development and conservation structures, improvements and upgrades to existing water distribution systems, dams and reservoirs, water sources for livestock and wildlife enhancement purposes, and fish-related structures. In some cases, Federal water rights have been expressly reserved to fulfill the purposes for which the areas were designated.

Non-Federal designated wilderness areas also provide high quality water to downstream communities. The Mission Mountains Tribal Wilderness (Figure 15), established by the Confederated Salish and Kootenai Tribes in 1982, was the first such tribally designated area in the United States (CSKT 2005). The 92,000-acre region in northwestern Montana is the source of some of the cleanest water on the Flathead Indian Reservation, and includes nine major streams and more than 100 lakes. The tribal community depends on this water for drinking, fishing, agriculture, the maintenance of spiritual and cultural traditions, and other uses.

Figure 15. Mission Mountains Tribal Wilderness, Flathead Indian Reservation, Montana (photo by Adam Johnson).

Non-Indian residents of the reservation also benefit from wilderness water for drinking and agriculture. Municipal watershed protection is given special consideration during the wilderness management decision-making process within the tribal government. For example, the town of Ronan, Montana, maintains a municipal water supply lease on Middle Crow Creek, which originates in the Mission Mountains Wilderness.

States have also set aside lands to protect water quality. For example, in 1892 the State of New York reserved a large area in the Adirondack Mountains, and one of the justifications for land preservation was the protection of valuable water resources (New York State 2012). The Adirondack Park was created amid concerns for the water and timber resources of the region. The park consists of approximately 6 million acres, more than 3,000 lakes, and 30,000 miles of rivers and streams. The state owns approximately 43 percent of the land within the Park's boundaries. The remaining private lands are devoted principally to forestry, agriculture, and open space recreation. Although the park is not officially designated as wilderness, water quality protection and remains a high priority in the Adirondacks.

Discussion And Conclusions: Wilderness Water Research Needs

Until recently, wilderness water discussions at the Federal level were generally limited to sections of publications concerning multiple wildland values or conference proceedings that focused on water quality impacts within the boundaries of individual wilderness areas. Recent research is beginning to refine our understanding of water resources in the areas of water supply and quantity, water quality, climate change impacts, and ecosystem services. The information reviewed in this paper illustrates the importance and increasing scarcity of high quality water resources across the nation. However, Pringle (2001) stressed the need for additional information about the contribution of wilderness to the protection of water quality, and noted a "lack of data on hydrologic connections between wilderness and surrounding areas…"

The Forests to Faucets project (Weidner and Todd 2011) identified forested areas that protect drinking water and regions where water supplies are threatened by development, wildfires, and insects and diseases. The study distinguished between all forested lands, NFS lands, unprotected private forests, and protected forest lands. Wilderness areas were considered in the analysis as part of the national Protected Areas Database. The authors created an Index of Protected Forest Importance to Surface Drinking Water, which explicitly recognizes the contribution of protected areas (including wilderness) to high-quality surface water for drinking purposes. However, the authors note that the results of the study are intended to provide broad-scale information across the country, and should not be used at the scale of individual watersheds. Additional basin-scale data and information is needed to understand connections between forests, drinking water sources, and threats to the forested areas.

Potential users of water research results include managers of wilderness lands and non-profit organizations that have asked for quantitative studies on the benefits of the resource. Work recently completed by Federal researchers is a partial response to such requests. Results of additional research can be used to better educate the public on the need for wilderness preservation and sound management. A high-visibility discussion (such as an article in Natural Areas Journal or a similar publication) may provide an avenue for receiving feedback regarding possible research approaches, recruitment of collaborators, and funding sources for projects.

New water resource valuation research could focus on multiple scales. In the broadest approach, values could be characterized across the country. Indeed, a major research need is the refinement of national water yield and value estimates on the national forests (USFS 2000), although more recent research by Tom Brown has provided some relevant information (Brown et al. 2005, 2008; Brown and Froemke 2009). Certainly, more refined estimates of wilderness water flows and values will be very useful. Alternatively, research on specific wildernesses or similarly managed areas (see case studies above) would undoubtedly also provide helpful information. For example, a study could be designed to rigorously quantify water volumes, water quality attributes, and economic values/benefits in one or more pilot wilderness study areas. More specifically, quantification of groundwater recharge to agricultural regions or urban zones from specific wilderness areas would provide significant insight into water valuation. Hydrogeologists and hydrologists could develop coupled surface water-groundwater conceptual and numerical models for one or more specific wilderness areas to quantify volumes and temporal variations in groundwater flows. These scientists could then work with natural resource economists to develop preliminary estimates of the value of the groundwater resources. Another study could highlight management needs to address existing unnatural fuel loads and address the effects of fire suppression that may be putting wilderness watersheds at increased risk of large, severe wildfires. Prescribed fires may be necessary in some cases to reduce risks to watershed function.

Water resources management strategies and research priorities vary across the agencies controlling wilderness lands. For example, the Forest Service is actively involved with developing plans for improving water resources protection and management within the National Forests, while the National Park Service maintains several significant service-wide programs concerning both water quality and water quantity protection. Development of an interagency panel of wilderness managers focused on water issues (similar to the Interagency Wild & Scenic Rivers Coordinating Council) may be one way to focus more attention on this important topic.

In summary, scientific research completed in the last several decades (and in the last 10 years in particular) has provided a framework for understanding the contributions and benefits of large volumes of high-quality water from wilderness areas for a variety of uses. However, much more can be done to improve our knowledge of the hydrologic characteristics of these areas and their contributions to economic and ecological vitality. As Pringle (2001) wrote, “the role of water, both aboveground and below the surface, must become a more integral consideration of wilderness integrity.”

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