Estimated mean annual contribution to water supply from designated wilderness in the coterminous United States

Thomas C. Brown and Pamela Froemke
Rocky Mountain Research Station
Fort Collins, Colorado

In the tables below we provide estimates by NFS (National Forest System) region of annual contribution to water supply from designated wilderness areas in the 48 contiguous states. These estimates were computed by overlaying wilderness area and other boundaries onto the spatially distributed estimates of water supply that were produced for a 2008 publication by Brown et al. about the source of the U.S. water supply.[1] To place the estimates of water supply originating in wilderness areas in perspective, we also provide estimates of water supply originating within the entire NFS and over the entire area regardless of land ownership.

For NFS land and for designated wilderness areas, two sets of boundary information are available, that from the National Atlas[2] and that from the ALP (Automated Lands Project) of the U.S. Forest Service.[3] In addition, two sets of NFS boundaries are available from the ALP, ownership boundaries and administrative (proclamation) boundaries. Administrative boundaries include in-holdings of private and other land. The National Atlas provides administrative boundaries. Lacking a preference for a particular boundary layer, we provide water supply and related land area estimates by region for the following areas:

- All land
- All NFS land based on administrative boundaries from the ALP
- All NFS land based on ownership boundaries from the ALP
- All designated wilderness based on boundaries from the National Atlas
- All designated NFS wilderness based on boundaries from the National Atlas
- All designated NFS wilderness based on ownership boundaries from the ALP

Total water amounts reported here may differ somewhat from those reported in Brown et al. because of changes in the boundary layers. For example, the total contribution from the NFS administrative units (based on the proclamation boundaries) reported here (329,525 million cubic meters per year) differs

[1] Brown, Thomas C., Michael T. Hobbins, and Jorge A. Ramirez. 2008. Spatial distribution of water supply in the coterminous United States. *Journal of the American Water Resources Association* 44(6):1474-1487, available at: www.fs.fed.us/rm/value/research_cpl.html.

[2] From the National Atlas we obtained the shape file "National Wilderness Preservation System of the United States", December 2005, available at www.nationalatlas.gov/mld/wildrnp.html.

[3] The ALP is an ongoing project of the Forest Service to, among other things, update GIS data of land boundaries. We obtained the ALP boundary shape files used here in July 2009. Some discrepancies exist between the ownership and administrative boundary layers because they were updated at different times.

from that reported in Brown et al. (325,691 Mm^3/yr) because of recent changes (both additions and corrections) to the ALP NFS boundary layer.[4]

Table 1 provides estimates of mean annual contribution to water supply for the eight NFS regions in the coterminous U.S. based on administrative (proclamation) boundaries available from the National Atlas and the ALP. Table 2 presents similar estimates based on ownership boundaries. Table 3 presents the respective land areas. Focusing on the administrative boundaries (Table 1), we see that 4.9% of the water supply of the 48 states originates on designated wilderness areas in an average year, and that 3.6% originates on wilderness areas in the NFS. About 18.6% of the total water supply originates on NFS lands, and 19.5% of that comes from wilderness areas.[5] The contribution of the NFS lands and NFS wilderness is most notable in Region 1 (76% and 18.3%, respectively), whereas the contribution of wilderness areas in general is most notable in Region 6 (18.7%).

The amount of water supply originating in a given wilderness area or other land area depends on the size of the area and the depth of the contribution to water supply per unit of area. Depth per unit area varies greatly across the landscape, ranging from essentially zero in the driest desert areas to over 1.5 meters per year in the wettest areas of the Pacific Northwest. Compared with the average depth for the entire coterminous U.S., of 229 mm/yr, the NFS contributes an average of 385 mm/yr, wilderness areas in general contribute an average of 453 mm/yr, and NFS wilderness areas contribute an average of 545 mm/yr (Table 4). Looked at another way, wilderness areas in general occupy only 2.5% of the land base (Table 3) but contribute 4.9% of the water supply of the coterminous U.S. (Table 1). The contribution of wilderness areas is most notable in Region 6 (Table 4).

Notice that the contribution to water supply from NFS lands is greater if computed using administrative boundaries than it is if computed using ownership boundaries (which is expected given that administrative boundaries include inholdings), but that the contribution from NFS wilderness lands is greater if computed using ownership boundaries than using administrative boundaries. This unexpected result occurs because the ownership boundary data are more current than the administrative boundary data. Because recent additions to the wilderness system are included in the ownership boundary data but not in the administrative boundary data, the contribution to water supply from wilderness areas computed using the administrative boundary data is an under-estimate.

A full explanation of the methodology used to estimate mean annual water supply is included in Brown et al. (2008). Here we briefly summarize some of the key points and qualifications:

- These estimates of mean annual contribution to water supply are based on data for 1953-94, which may not represent current or future hydrologic conditions.
- There is considerable year-to-year variation about the means reported here, variation that is not at all evident in the means.

[4] For the analysis we converted the ALP and National Atlas polygons and the 5 km water supply grid to congruent 250 m grids.

[5] When the NFS area is restricted to the land actually owned, wilderness areas are estimated to contribute 24.1% of the total NFS contribution to the water supply of the 48 states (Table 2).

- "Water supply" as used here was computed as precipitation minus natural evapotranspiration. (Evaporation occurs as water evaporates from soil and vegetation surfaces. Transpiration occurs as vegetation gives up water vapor to the atmosphere through small openings called stomata, principally in the process of photosynthesis.) Estimating water supply in this way makes the assumption that water entering the soil that is not evaporated or transpired eventually becomes available for use either by naturally returning to the surface at some point downstream or by being pumped to the surface.
- Evapotranspiration was estimated using computer models that rely on data from weather stations (for variables such as solar radiation, wind speed, and humidity). Values of weather variables for areas between stations were estimated by spatial interpolation. In addition, precipitation for areas between weather stations was estimated. Weather stations are particularly sparse in mountainous areas of the West. This estimation between stations introduces errors in the estimates of water supply. Such errors are more likely when applying the model to small areas, which may contain few or no weather stations within the boundary.
- In selected watersheds—relatively pristine watersheds that have stream gages at the outlet—the models were tested for accuracy and were further refined by comparing predicted water supply to measured streamflow. Natural discharge data were lacking for some areas of the U.S., especially in drier portions of the West, which hampered testing and refinement and may introduce errors.
- The estimates of water supply for wilderness area could not be tested for accuracy because of the lack of strategically located stream gages.

Table 1. Mean annual contribution to water supply based on administrative boundaries

Region	Water volume (million m^3/yr)				Percent of total (all area) volume originating in:			% of NFS[a]
	All area	NFS	All W[b]	NFS W	NFS	All W	NFS W	NFS W
1	68,124	51,772	12,489	12,462	76.0	18.3	18.3	24.1
2	71,614	20,460	7,270	7,185	28.6	10.2	10.0	35.1
3	10,195	5,077	995	953	49.8	9.8	9.4	18.8
4	66,464	36,804	8,429	8,385	55.4	12.7	12.6	22.8
5	93,047	42,142	13,371	8,373	45.3	14.4	9.0	19.9
6	210,931	90,912	39,518	23,471	43.1	18.7	11.1	25.8
8	666,341	51,311	2,556	1,813	7.7	0.4	0.3	3.5
9	580,898	31,048	1,870	1,770	5.3	0.3	0.3	5.7
Total	1,767,613	329,525	86,499	64,411	18.6	4.9	3.6	19.5

[a] Percent of water supply originating on NFS land that originates in wilderness areas

[b] W = wilderness

Table 2. Mean annual contribution to water supply based on ownership boundaries

Region	Water volume (million m^3/yr)			% of total volume originating in:		% of NFS[a]
	All area	NFS	NFS W[b]	NFS	NFS W	NFS W
1	68,124	48,119	12,815	70.6	18.8	26.6
2	71,614	19,015	7,119	26.6	9.9	37.4
3	10,195	4,810	939	47.2	9.2	19.5
4	66,464	34,622	8,638	52.1	13.0	24.9
5	93,047	35,863	8,981	38.5	9.7	25.0
6	210,931	83,855	23,345	39.8	11.1	27.8
8	666,341	27,747	1,803	4.2	0.3	6.5
9	580,898	17,862	1,872	3.1	0.3	10.5
Total	1,767,613	271,892	65,511	15.4	3.7	24.1

[a] Percent of water supply originating on NFS land that originates in wilderness areas in the NFS

[b] W = wilderness

Table 3. Land area (km^2)

Region	All area	NFS ALP Admin[b]	NFS ALP Owner[c]	All W National Atlas	NFS W National Atlas	NFS W[a] ALP Owner
1	630,724	119,373	101,917	20,239	19,783	20,404
2	1,066,056	112,593	88,178	20,416	19,176	19,161
3	608,291	93,632	81,906	24,970	11,101	10,939
4	714,274	137,950	128,587	27,180	21,847	23,063
5	392,073	95,274	81,556	55,571	17,722	18,206
6	414,817	110,977	99,933	27,180	19,146	19,068
8	2,185,002	100,349	53,906	8,862	2,953	2,905
9	1,697,191	85,213	48,259	6,634	6,395	5,366
Total	7,708,427	855,361	684,241	191,052	118,123	119,113

[a] W = wilderness

[b] Admin = administrative (proclamation) boundaries

[c] Owner = ownership boundaries

Table 4. Average depth of contribution to water supply (mm/yr)

Region	All area	NFS ALP Admin[b]	NFS ALP Owner[c]	All W National Atlas	NFS W National Atlas	NFS W[a] ALP Owner
1	108	434	472	617	630	628
2	67	182	216	356	375	372
3	17	54	59	40	86	86
4	93	267	269	310	384	375
5	237	442	440	241	472	493
6	508	819	839	1,454	1,226	1,224
8	305	511	515	288	614	621
9	342	364	370	282	277	349
All	229	385	397	453	545	550

[a] W = wilderness

[b] Admin = administrative (proclamation) boundaries

[c] Owner = ownership boundaries