Drought-Vulnerability Assessment of Public Water Systems in West Virginia

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U.S. Department of the Interior
U.S. Geological Survey

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By Matthew R. Kearns, Kaycee E. Faunce, and Terence Messinger

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic decimeter (dm^3)	0.2642	gallon (gal)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Abbreviations

1Q10	1-day, 10-year hydrologically based flow
IS-6	Incident Specific Annex 6
LQU	Large Quantity User
NWM	National Water Model
PWS	public water system
USGS	U.S. Geological Survey
WVDEM	West Virginia Division of Emergency Management
WVDEP	West Virginia Department of Environmental Protection
WVDHHR	West Virginia Department of Health and Human Resources

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Abstract

Water withdrawn from rivers and streams accounts for approximately 80 percent of the public water supply in West Virginia. Localized and (or) seasonal droughts may threaten future water availability in the state, particularly in rural communities located in the headwaters of unregulated watersheds. Monthly water withdrawal data obtained from the West Virginia Department of Environmental Protection's Large Quantity User program's regulatory database was used to calculate all-time, seasonal, and monthly 75th quantile withdrawal rates for 109 public water system (PWS) intakes withdrawing from surface waters in West Virginia. A drought-vulnerability assessment value was calculated by comparing PWS withdrawal rates to the 1-day, 10-year hydrologically based streamflow statistic (1Q10) for 71 of the 109 PWS in locations with valid streamflow statistics. Withdrawal rates were evaluated against thresholds representing different levels of drought-related impacts from the West Virginia interagency drought plan and ecological-flow literature. The drought-vulnerability assessment found 33 of 71 PWS have 75th quantile withdrawal rates greater than 100 percent of 1Q10 streamflow. Forty-five of 71 PWS have 75th quantile withdrawal rates more than 10 percent of 1Q10 streamflow, suggesting some level of ecological impairment during severe drought. Additionally, a publicly available, near real-time drought-awareness web tool was created to compare the estimated withdrawal rate for 109 PWS with forecast streamflows from the National Water Model to support decision-making for emergency and water managers.

Introduction

Approximately 80 percent of West Virginia's public water supply comes from rivers and streams (Dieter and others, 2018; West Virginia Department of Environmental Protection, 2022). Although Appalachia historically has enjoyed an abundance of water across large geographical and temporal scales, localized and (or) seasonal drought conditions do occur. In October 2019, 50 percent of the state experienced moderate to severe drought and the remainder experienced abnormally dry conditions, resulting in the Governor of West Virginia declaring a drought emergency (Justice, 2019; National Drought Mitigation Center, 2022). Furthermore, regional climate modeling suggests that seasonal droughts may increase in frequency or severity throughout much of West Virginia because of increased evapotranspiration and aridity driven by rising temperatures (Fernandez and Zegre, 2019).

Drought impacts are not experienced uniformly across the state. The public water systems (PWS) of West Virginia's largest municipalities are located along or near major watercourses with streamflow regulated by dams. These municipalities are likely to be affected only during the most severe or prolonged droughts. The PWS in smaller, rural communities located in the headwaters of unregulated watersheds may be at the greatest risk for drought-related supply shortfalls, as suggested by local reporting from the 2019 drought (Steelhammer, 2019).

Although there are several metrics and indices to measure the meteorological and hydrologic severity of drought, there is less understanding of when these environmental conditions begin to have societal impact (Bachmair and others, 2016). This report uses local data and nationally available models to provide a basic understanding of PWS drought vulnerability in West Virginia. Additionally, a monitoring tool was developed to help West Virginia's emergency, environmental, and public health managers at the Federal, State, and local levels with drought planning, forecasting, or decision making.

Purpose and Scope

This report documents a drought-vulnerability assessment and the methods used to create a near real-time drought-awareness web tool for West Virginia PWS. This analysis informs at-risk municipalities and the Federal and State agencies tasked with drought response under the direction of West Virginia Division of Emergency Management's Incident Specific Annex 6 (IS-6) drought guidelines (West Virginia Division of Emergency Management, 2016). These agencies include the National Weather Service, West Virginia Department of Environmental Protection (WVDEP), West Virginia Department of Health and Human Resources (WVDHHR), and West Virginia Division of Emergency Management (WVDEM), all of which cooperated on this study.

Description of Study Area

West Virginia is located among the Appalachian Mountains of the eastern United States. River systems west of the eastern continental divide drain into the Ohio River watershed; river systems east of the eastern continental divide drain into the Chesapeake Bay watershed. The state has a continental climate with an average of 45 inches of precipitation annually: spring and early summer are the wettest periods of the year; late summer and fall are the driest periods of the year (Wiley and Atkins, 2010). Runoff from precipitation is the primary surface water source for 109 PWS, comprising approximately 80 percent of all PWS withdrawals by volume (West Virginia Department of Environmental Protection, 2022). Most of West Virginia's biggest municipalities utilize source water from large river systems with multi-purpose dams actively managed by the U.S. Army Corps of Engineers. However, there are dozens of smaller communities located higher in the watersheds of West Virginia's mountainous terrain, upstream from active flow regulation or management structures, which are heavily reliant upon natural streamflow for their water supply. These PWS are the focus of the drought vulnerability-assessment and are shown in figure 1.

Study Methods

The drought-vulnerability assessment compares PWS surface water withdrawal rates derived from a WVDEP regulatory database against U.S. Geological Survey (USGS) streamflow statistics (Wiley, 2008). A higher ratio of PWS water withdrawal to low-flow water availability suggests greater vulnerability during drought conditions. To support decision-making for water resource managers, the ratio of PWS surface-water withdrawals to forecast streamflows from the National Water Model (NWM; Cosgrove and Gochis, 2018; Cosgrove and Klemmer, undated) are calculated and are publicly available through a near real-time drought-awareness web tool (https://rconnect.usgs.gov/wv-surface-withdrawals/).

Drought-Vulnerability Assessment

Water Withdrawal Rates

Monthly water-withdrawal information was obtained upon request from the WVDEP Large Quantity User (LQU) program, which requires annual reports from all water users that withdraw more than 300,000 gallons per month from West Virginia's water resources (West Virginia Department of Environmental Protection, 2022). The LQU database was filtered to include only those PWS intakes using surface water sources, with at least two years of available data, and still in operation as of 2022. PWS intakes using springs and groundwater wells were excluded from the study, as these water sources are not comparable with USGS streamflow statistics. With these restrictions in place, the database yielded LQU data from 2003 onwards; data collected from 2014 through 2020 were judged most consistent, due to regulatory and reporting changes over time. Quality-control checks of data, including basic plots and summary statistics, identified infrequent errors that were subsequently corrected. The most common identifiable error (3.5 percent of PWS) stemmed from water operators submitting annual reports with monthly withdrawals recorded in "thousands of gallons" and not "gallons" as the LQU program requests. The error was discoverable as a three-orders-of-magnitude stepwise change in water use from year to year.

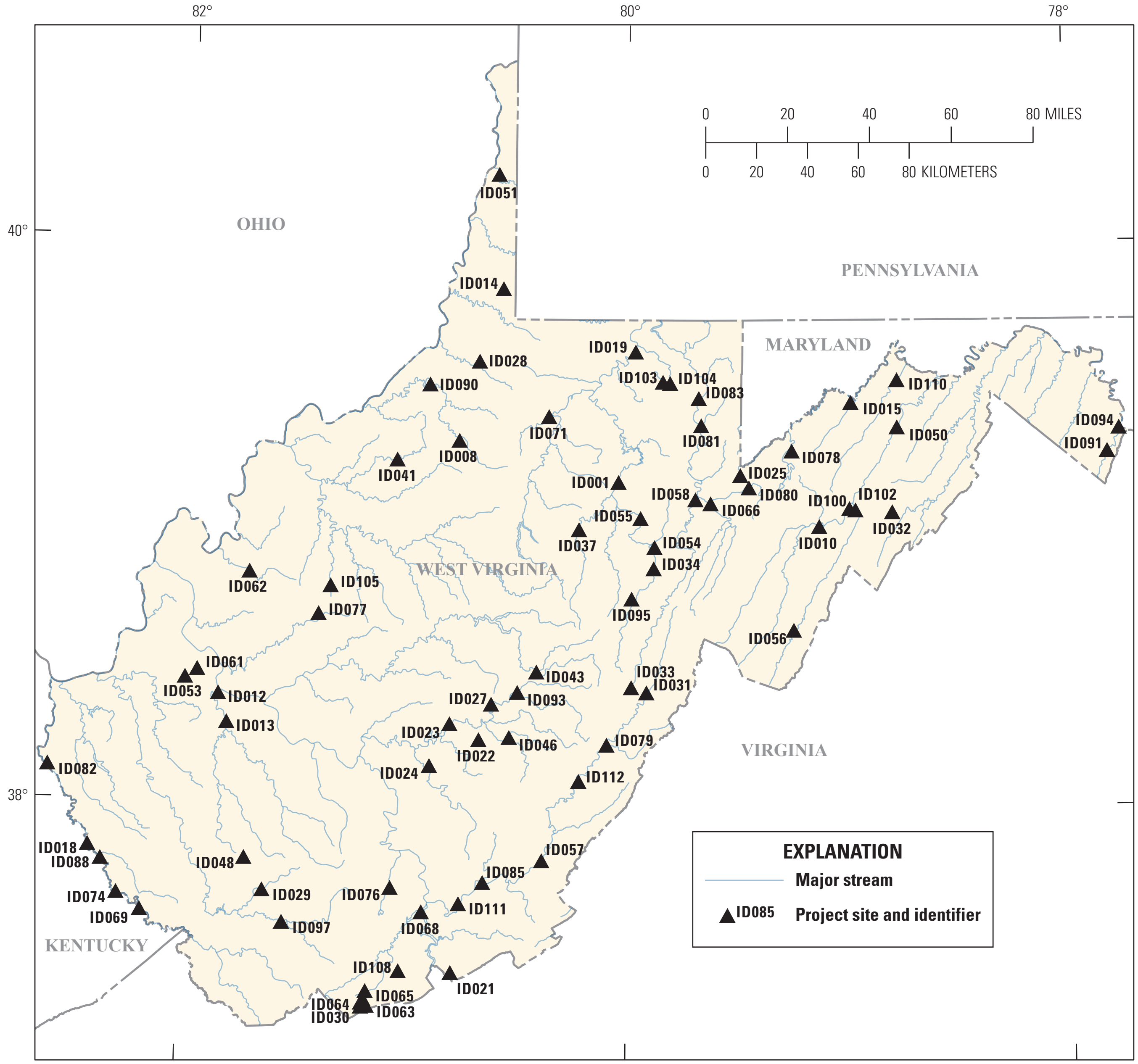
To safeguard PWS identities in accordance with USGS guidance (N. Booth, U.S. Geological Survey, written commun., 2014), each PWS withdrawal intake was given a unique identifier (Project ID) specific to this project. Each PWS intake's reported monthly withdrawal in gallons was converted to cubic feet per second (ft^3/s), assuming a constant withdrawal rate throughout a given month and a conversion factor of 7.4805 gallons to 1 cubic foot. Five PWS with redundant intakes on the same waterbody (a "primary" and "secondary") were assumed to use only the primary intake. For this assessment, any withdrawals reported from a secondary intake were added to the primary intake withdrawal and the secondary intakes (ID007, ID073, ID084, ID098, ID101) were removed from the analysis. Failure to complete this step for these systems would artificially lower the ratio of withdrawal rate to streamflow during subsequent analysis.

The open-source statistical programming language "R" (version 4.0.3, R Core Team, 2020) was used to derive and plot all-time (2014–2020), seasonal, and monthly summary statistics for each PWS intake's withdrawal rate. Upon review of time-series and box plots, and in consultation with State-agency cooperators, the 75th quantile withdrawal rate was selected as the best representation of water use for the drought-vulnerability assessment and web tool. The all-time 75th quantile withdrawal rate is representative of the typical seasonal increase in PWS withdrawals during the summer months when drought is most likely. On seasonal or monthly scales, the 75th quantile withdrawal rate represents moderately high-use scenarios while also avoiding outlier withdrawal rates. Outlier values are likely related to water system leaks and maintenance (West Virginia Department of Environmental Protection, 2022).

All PWS monthly withdrawal volumes and calculated withdrawal rates included in this study are available from Kearns and Faunce (2023).

Streamflow Statistics

Specific locations of PWS withdrawal intakes were provided by State-agency cooperators for this analysis but are not included in any subsequent report, data release, or web tool to comply with USGS guidance (N. Booth, U.S. Geological Survey, written commun., 2014) and West Virginia



Base from State of West Virginia, U.S. Geological Survey,
and Esri and its licensors, copyright 2023; Albers Equal-Area Conic projection,
standard parallels 36°40' and 39°20' N, central meridian 79°30' W
North American Datum of 1983

Figure 1. Map showing approximate locations of 71 surface water withdrawal intakes for public water systems in West Virginia included in the drought-vulnerability assessment.

state law (West Virginia Legislature, 2023). Coordinates for each PWS withdrawal intake were visually compared to satellite and aerial imagery for accuracy and corrected as needed. Coordinates for 19 percent of the PWS intakes were corrected, resulting in locations changing by more than 100 meters. PWS withdrawal intakes were then assigned to the nearest 10-meter stream-grid cell used by the USGS StreamStats batch-processing application (U.S. Geological Survey, 2022). StreamStats solves regional regression equations to estimate annual and seasonal low-flow statistics (Wiley, 2008; Wiley and Atkins, 2010). Drainage-area transfer equations were used to estimate streamflow for streams with published streamgage statistics, and regional-regression equations were used to estimate streamflow for ungaged and gaged streams without published streamgage statistics (Wiley 2006; Wiley, 2008).

Streamflow estimates derived from low-flow regression equations or drainage-area transfer from streamgage statistics computed from unregulated periods of record are not valid on regulated streams (Wiley, 2008). Of the 109 PWS surface-water intakes in this study, 38 are located below dams with active flow regulation, as determined by a WVDEP-provided watershed flow tool (Technical Applications and GIS Unit, undated). Therefore, these 38 PWS are excluded from the drought-vulnerability assessment but are included in the near real-time drought-awareness web tool, which does not use the low-flow stream statistics.

From the regression and drainage-area transfer equations, the 1-day, 10-year hydrologically based streamflow (1Q10) statistic was selected as the best available representation of a severe drought. The 1Q10 statistic is the minimum average one-day streamflow expected (on average) once every 10 years (Wiley, 2008). The 1Q10 is the lowest-magnitude streamflow statistic currently available for West Virginia. Droughts at intervals with a lower probability of occurrence (for example 20-, 50-, or 100-year droughts) would all be expected to have lower magnitudes than the 1Q10 streamflow statistic.

The drought-vulnerability assessment described in this report uses a simple assumption: a PWS that withdraws a greater percentage of the available streamflow is more likely to be impacted by droughts. The 75th quantile of all monthly withdrawal rates (2014–2020) was divided by the 1Q10 streamflow statistic to derive a withdrawal to streamflow ratio (table 1). These 75th quantile withdrawal to 1Q10 streamflow ratios are the drought-vulnerability assessment: the greater the ratio, the greater vulnerability of the PWS to drought, and the greater the potential impact on human and (or) ecological systems during drought. Variations in drought vulnerability due to seasonal fluctuation of both 1Q10 (Wiley and Atkins, 2010) and the PWS 75th quantile withdrawal rate are provided in appendix 1.

Near Real-Time PWS Drought-Awareness Web Tool

Although the drought-vulnerability assessment suggests the likelihood of a drought impacting a PWS, it does not provide the real-time information that emergency managers, water utilities, and others need to make decisions regarding potential impacts of drought on the water supply. West Virginia's interagency drought plan (West Virginia Division of Emergency Management, 2016) states that water-conservation measures should be enacted whenever water withdrawals exceed 25 percent of streamflow. However, there is no real-time PWS withdrawal rate reporting requirements and the majority of PWS considered by this report do not occur on stream reaches where continuous streamflow monitoring is available to inform these decisions. To increase awareness of those actionable drought-management thresholds, the PWS withdrawal rates used to assess drought vulnerability are leveraged in a publicly available web tool that calculates and displays PWS water-withdrawal ratios using hourly streamflow estimates from the NWM short-range forecasts (Cosgrove and Gochis, 2018; Cosgrove and Klemmer, undated).

The NWM is a hydrologic model built upon the Weather Research and Forecasting Model (WRF-Hydro; Gochis and others, 2013) that incorporates real-time meteorological data, reservoir levels, and measured streamflows from the USGS and U.S. Army Corps of Engineers gages (Cosgrove and Gochis, 2018). The NWM simulates water movement for 2.7 million river reaches of the 1:100,000 scale National Hydrology Dataset Plus Version 2.1 (NHDPlus; U.S. Environmental Protection Agency, 2012). NWM short-range forecasts are updated hourly and fill spatial gaps where monitored streamflow data are not available.

Because assumptions regarding actively managed and regulated flows are not present in the NWM, 38 PWS withdrawal intakes excluded from the drought-vulnerability assessment are included in the drought-awareness web tool. The web tool subsequently shares information for 109 PWS withdrawal intakes. To link PWS intakes with the NWM, each PWS intake location was assigned to the nearest NHDPlus stream reach with a valid NWM output. Four PWS (ID048, ID054, ID061, ID068) did not return a valid NWM output ("-9999," indicating missing data in the model) and were instead linked to the nearest downstream stream reach with a valid output. Once assigned a reach, the forecasted streamflow is evaluated against the PWS intake's 75th quantile withdrawal rate for the applicable month.

The web-tool user interface groups PWS by county or watershed (10-digit hydrologic code, HUC10; U.S. Environmental Protection Agency, 2012) without showing specific PWS intake locations, which could conflict with USGS guidance (N. Booth, U.S. Geological Survey, written commun., 2014) and West Virginia state law (West Virginia Legislature, 2023). A user selects a county or watershed in the web tool, and information for each PWS within that area is provided in an information panel. The information panel displays the estimated PWS withdrawal rate (75th quantile of historical monthly withdrawal rate), current short-range NWM streamflow forecast for the reach associated with the intake, the estimated-withdrawal to forecast-streamflow ratio, and other relevant information regarding the source waters for each PWS in the selected area. Information in the tool is updated hourly to coincide with the frequency of NWM short-range forecast updates.

The web tool's user interface is color-coded for easy identification of potential PWS drought-related impacts. Estimated PWS 75th quantile monthly withdrawals greater than 25 percent of NWM forecast streamflow (the conservation threshold from WVDEM IS-6) are used as the uppermost category, displayed in orange. Estimated PWS 75th quantile monthly withdrawals between 10 to 25 percent of NWM forecast streamflow were selected as an intermediate category

Table 1. Drought-vulnerability assessment of 71 selected public water systems in West Virginia.

[ID, identifier; mi^2, square mile; 1Q10, 1-day, 10-year hydrologically based flow; ft^3/s, cubic feet per second; WD, withdrawal; 75th WD/1Q10, 75th quantile withdrawal to 1-day, 10-year hydrologically based flow ratio; *, “divide by zero” error in 75th WD/1Q10 ratio; NA, not available; —, null values; contents organized from highest risk (greatest ratio) to lowest risk (smallest ratio)]

Project ID	Station name	Drainage area[1] (mi^2)	1Q10[2] (ft^3/s)	75th quantile WD[3] (ft^3/s)	75th WD/1Q10 ratio (percent)	On-stream storage[4]	Reservoir storage[5] (acre-feet)
ID014	Intake on Cameron Reservoir 19454517	0.4	0	0.1429	*	Reservoir	6
ID025	Intake on North Fork Blackwater River 3775885	1.19	0	0.1615	*	Reservoir	59
ID030	Intake on J.P. Bailey Reservoir 6909475	1.05	0	0.2768	*	Reservoir	250
ID053	Intake on Hurricane Creek 19315460	5.3	0	0.8994	*	Reservoir	61
ID061	Intake on Poplar Fork 19315530	9.91	0	5.0591	*	Reservoir	36
ID063	Intake on Ada Reservoir 6909509	1.25	0	1.0665	*	Reservoir	240
ID064	Intake on Horton Reservoir 6909515	1.02	0	1.5558	*	Reservoir	380
ID071	Intake on Jones Run 3715724	10.3	0	0.3314	*	Reservoir	NA
ID077	Intake on Silcott Fork 19313070	3.26	0	0.2208	*	Reservoir	200
ID103	Intake on Fairfax Pond 3770326	1.99	0	0.4615	*	Reservoir	37
ID104	Intake on Deckers Creek 3768762	4.71	0	0.4586	*	Reservoir	96
ID105	Intake on Charles Fork 19419681	3.98	0	1.1024	*	Reservoir	1,600
ID019	Intake on Cobun Creek 3768582	11.7	0.02	5.8165	29,100	Reservoir	190
ID062	Intake on Mill Creek 19442441	135	0.01	1.6513	16,500	Weir	—
ID033	Intake on Shavers Lake 3777389	2.78	0.01	0.732	7,320	Reservoir	NA
ID076	Intake on Glade Creek 6920946	25.8	0.2	11.7217	5,860	Reservoir	1,900
ID041	Intake on North Fork Hughes River 19414131	79	0.02	0.8746	4,370	Reservoir	3,700
ID065	Intake on Kee Reservoir 6909439	2.08	0.01	0.3027	3,030	Reservoir	970
ID040	Intake on Laurel Creek Reservoir 6909139	5.32	0.03	0.6853	2,280	Reservoir	280
ID108	Intake on Glenwood Lake 6909327	10.9	0.07	1.484	2,120	Reservoir	1,600
ID022	Intake on Panther Creek 4546776	11.5	0.07	0.6472	925	Weir	—
ID008	Intake on Middle Island Creek 15432570	110	0.07	0.4255	608	Weir	—
ID048	Intake on Buffalo Creek 6933832	13.4	0.09	0.5437	604	Weir	—
ID028	Intake on North Fork Fishing Creek 15429208	42.2	0.02	0.1041	521	Weir	—
ID046	Intake on North Fork Cherry River 4546774	35.8	0.31	1.2064	389	Weir	—
ID054	Intake on Tygart Valley River 4352968	268	0.85	3.1977	377	Reservoir	140
ID078	Intake on Mill Run 14365556	4.97	0.07	0.2492	356	Reservoir	88
ID095	Intake on Mill Creek 4352790	16.1	0.11	0.2824	257	Weir	—
ID037	Intake on Buckhannon River 4353190	197	1.42	3.3669	237	Weir	—
ID029	Intake on Laurel Fork 6934372	56.2	0.54	1.0103	187	—	—
ID051	Intake on Buffalo Creek 19451633	148	0.2	0.2896	145	—	—
ID015	Intake on New Creek 14364804	52.1	1.4	1.5294	109	—	—
ID094	Intake on Elk Run 5894528	17.9	0.34	0.3472	102	—	—
ID090	Intake on Middle Island Creek 15431930	355	0.19	0.1528	80	—	—
ID027	Intake on Gauley River 4545684	73	0.76	0.5452	72	—	—
ID032	Intake on Parker Hollow Reservoir 8433336	6.91	0.1	0.0609	61	Reservoir	NA
ID031	Intake on Leatherbark Creek 12103894	6.73	0.04	0.0232	58	Weir	—
ID100	Intake on South Fork South Branch Potomac River 8419916	285	8.77	4.9923	57	Weir	—
ID034	Intake on Tygart Valley River 4352996	219	0.84	0.4663	56	—	—

Table 1. Drought-vulnerability assessment of 71 selected public water systems in West Virginia.—Continued

[ID, identifier; mi^2, square mile; 1Q10, 1-day, 10-year hydrologically based flow; ft^3/s, cubic feet per second; WD, withdrawal; 75th WD/1Q10, 75th quantile withdrawal to 1-day, 10-year hydrologically based flow ratio; *, "divide by zero" error in 75th WD/1Q10 ratio; NA, not available; —, null values; contents organized from highest risk (greatest ratio) to lowest risk (smallest ratio)]

Project ID	Station name	Drainage area[1] (mi^2)	1Q10[2] (ft^3/s)	75th quantile WD[3] (ft^3/s)	75th WD/1Q10 ratio (percent)	On-stream storage[4]	Reservoir storage[5] (acre-feet)
ID024	Intake on Meadow River 4547418	289	1.01	0.4741	47	—	—
ID093	Intake on Gauley River 4545948	245	2.68	0.7731	29	—	—
ID097	Intake on Guyandotte River 6934966	203	2.77	0.7046	25	—	—
ID110	Intake on Patterson Creek 14368832	253	4.83	0.7873	16	Weir	—
ID055	Intake on Tygart Valley River 4351508	408	2.89	0.3967	14	—	—
ID023	Intake on Gauley River 4548030	611	11.73	1.5427	13	Reservoir	190,000
ID001	Intake on Tygart Valley River 4352184	916	18.8	1.9492	10	Weir	—
ID012	Intake on Coal River 6929054	887	20.33	2.0553	10	—	—
ID057	Intake on Greenbrier River 12107418	1,010	30.51	3.0785	10	—	—
ID080	Intake on Blackwater River 3774989	60.6	2.29	0.2091	9	Reservoir	NA
ID074	Intake on Tug Fork 435154	935	33.94	2.9522	9	Weir	—
ID079	Intake on Knapps Creek 12104384	108	3.78	0.311	8	—	—
ID088	Intake on Tug Fork 434794	1,040	22	1.7349	8	—	—
ID013	Intake on Coal River 6928118	830	16.6	0.7953	5	—	—
ID058	Intake on Shavers Fork 3780353	211	8.9	0.3292	4	—	—
ID083	Intake on Cheat River 3775677	1,010	35.64	1.1584	3	—	—
ID043	Intake on Elk River 19323513	170	6.28	0.204	3	—	—
ID056	Intake on South Fork South Branch Potomac River 8423472	101	2.3	0.0609	3	—	—
ID068	Intake on Bluestone Lake 6906551	4,620	146	3.8848	3	Reservoir	38,000
ID010	Intake on South Branch Potomac River 8421608	656	72.9	1.4569	2	Weir	—
ID066	Intake on Dry Fork 3775187	347	9.22	0.1789	2	—	—
ID069	Intake on Tug Fork 435286	854	32.77	0.5938	2	—	—
ID018	Intake on Tug Fork 434540	1,280	39.12	0.6557	2	—	—
ID085	Intake on Greenbrier River 12107522	1,330	43.44	0.6484	1	—	—
ID082	Intake on Tug Fork 433830	1,560	44.63	0.4274	1	Weir	—
ID091	Intake on Shenandoah River 8445112	3,010	298.78	2.6928	1	—	—
ID050	Intake on South Branch Potomac River 8420162	1,400	86.9	0.7487	1	—	—
ID081	Intake on Cheat River 3775731	936	34.14	0.2159	1	—	—
ID112	Intake on Greenbrier River 12105110	624	11.5	0.0554	0	—	—
ID111	Intake on Greenbrier River 12107566	1,560	47.23	0.1735	0	—	—
ID021	Intake on Rich Creek 6907585	26.6	0.21	0.0002	0	—	—
ID102	Intake on South Branch Potomac River 8420282	888	56.53	0.0593	0	—	—

[1] Drainage area from USGS StreamStats (U.S. Geological Survey, 2022).

[2] 1Q10 computed using methods from Wiley (2008).

[3] WD calculated as the 75th quantile of all reported monthly withdrawals 2014–2020 (West Virginia Department of Environmental Protection, 2022).

[4] On-stream storage indicated as either "reservoir" suggesting documented impoundment or "weir" suggesting a smaller in-stream control structure.

[5] Reservoir storage data from National Inventory of Dams (U.S. Army Corps of Engineers, 2023).

displayed in yellow. Estimated PWS 75th quantile monthly withdrawals less than 10 percent of NWM forecast streamflow are colored green. The 10 percent streamflow-withdrawal threshold was selected as a "presumptive standard" from the literature of ecological-flow science, which suggests that in the absence of more detailed analysis, an utilization rate of no more than 10 percent of streamflow offers high ecological protection for aquatic habitats (Richter and others, 2012). Counties or watersheds with more than one PWS intake are represented by the PWS intake with the greatest estimated withdrawal to streamflow ratio. Information for all PWS in the web tool is also summarized in a downloadable data table, organized from the PWS with the greatest estimated-withdrawal to forecast-streamflow ratio to the least.

Withdrawal-rate data and ancillary information for PWS used by the web tool are available from Kearns and Faunce (2023). The near real-time PWS drought-awareness web tool is available at https://rconnect.usgs.gov/wv-surface-withdrawals/.

Discussion of Drought-Vulnerability Assessment

The drought-vulnerability assessment (the ratio of 75th quantile PWS withdrawals to 1Q10 streamflow statistic) suggests that 33 of the 71 PWS (46 percent) have 75th quantile withdrawal rates greater than 100 percent of available low-flow streamflow (table 1). Twelve of these 33 PWS have a 1Q10 of zero, indicating that they may not have any available streamflow during low-flow events that approach or exceed the 1Q10. Forty-one of the 71 PWS (58 percent) have 75th quantile withdrawal rates that exceed the 25 percent threshold of 1Q10 streamflow in WVDEM IS-6 that may trigger additional considerations for water conservation.

Six of 71 PWS have 75th quantile withdrawal to 1Q10 streamflow ratios between 10 and 25 percent. While this range does not exceed the water-conservation threshold from WVDEM (25 percent), it is above the 10 percent presumptive standard for ecological protection of streamflow, suggesting potential impairment of aquatic habitat during drought (Richter and others, 2012). Additionally, 13 PWS with 75th quantile withdrawal rates exceeding 10 percent of 1Q10 streamflow are without any on-stream water storage, suggesting limited options for the PWS to mitigate the social or ecological impact of a severe drought.

Seasonal variability in both 75th quantile withdrawals and 1Q10 low-flow statistics suggests that the highest 75th quantile withdrawal to 1Q10 streamflow ratios—and the greatest drought risk—occurs in summer (July to September) and continues to a slightly lesser extent into the fall (October to December; appendix 1). The primary driver of increased seasonal risk is the sharp decline in the 1Q10 streamflow statistic during the summer and fall months.

Limitations of Drought-Vulnerability Assessment

The withdrawal rates and 1Q10 streamflow statistics used in this drought-vulnerability assessment are estimates created from statistical analysis of available data. The ratios derived from these statistics represent a hypothetical condition. The 75th quantile of all reported monthly withdrawals was used to represent a moderately-high water demand scenario that could be expected during drought-like conditions while avoiding outliers resulting from system leaks or other anomalies. A "normal" (median or average) withdrawal rate would likely be lower than the 75th quantile value and may have resulted in an underestimate of drought vulnerability.

The 1Q10 low-flow statistic was selected as the best representation of a severe drought. It is the smallest magnitude low-flow statistic with available estimates and equations; however, historical data suggest that streamflow during extreme droughts may be well below the 1Q10 and therefore underestimated by the drought-vulnerability assessment. For example, the 1Q10 at a USGS streamgage on the Tygart Valley River (USGS site 03054500) is 9.37 $\mathrm{ft^3/s}$ and the minimum flow on record is 4.90 $\mathrm{ft^3/s}$ on October 10, 1953 (Wiley, 2006). As another example, the Big Coal River at Ashford, West Virginia (USGS Site 03198500) with a 1Q10 of 4.76 $\mathrm{ft^3/s}$ recorded zero flow for over a week in late September 1930 (Wiley, 2006). Tree ring studies in the Potomac River watershed, which includes eastern West Virginia, contain evidence of droughts more severe than anything in the period of record for streamgage instrumentation (Maxwell and others, 2011).

Thirty-eight of the 109 PWS withdrawal intakes are below actively managed dams where regulated streamflow does not follow natural patterns. Such conditions did not meet the basic assumption of the available low-flow estimation methods, so these PWS were excluded from the drought-vulnerability assessment. However, many stream control and storage structures on smaller rivers and streams without reported flow regulation were noted while reviewing databases, geospatial information, and satellite and aerial imagery for the remaining 71 PWS. These structures may provide low-flow augmentation for PWS. As used in this report, a "reservoir" includes a documented impoundment, and a "weir" suggests a smaller in-stream "run-of-river" control structure. Twenty-five reservoirs and 15 weirs were noted. These structures are noted with the drought-vulnerability assessment to provide additional context for high withdrawal rates, which could be sustained during low-flow scenarios given enough water storage. Table 1 includes the normal water storage for reservoirs (in acre-feet) from the National Inventory of Dams (U.S. Army Corps of Engineers, 2023). Estimating the amount of water storage for other in-stream structures is beyond the scope of this assessment.

Limitations of Near Real-Time Drought-Awareness Web Tool

The greatest limitation of the web tool is the relatively static nature of the estimated PWS withdrawal rate (75th quantile of historical monthly withdrawal rates) in comparison to the hourly updates of the NWM short-range streamflow forecast. Monthly PWS withdrawal volumes are the best available information under current regulatory and reporting requirements. Monthly PWS withdrawal volumes were converted to monthly PWS withdrawal rates assuming a constant operating schedule (24 hours a day, 7 days a week) and the lowest possible withdrawal rate to meet the reported withdrawal volume. A PWS withdrawing the same volume of water over a shorter period (for example, an 8- or 12-hour workday) could drastically increase the actual withdrawal rate over the estimated rate used in the web tool. Additionally, on-stream water storage at some PWS intake sites can skew the forecast streamflow and (or) sustain high estimated withdrawal to forecast streamflow ratios.

By incorporating the NWM short-range streamflow forecasts, the web tool also contains any assumptions, limitations, uncertainty, or errors present in the NWM and the datasets and models (such as WRF-Hydro) the NWM is built upon. At the time of this report's publication, the NWM continues updates and versioning. The National Oceanic and Atmospheric Administration's Office of Weather Prediction considers the current NWM "experimental" and not an official river level forecast. The authors acknowledge these limitations and recognize the difficulty of modeling and forecasting streamflow without continuous, real-time monitoring on every stream reach. The NWM, however, represents the best available near real-time estimates of ungaged streams at state-wide scale. While the NWM offers multiple streamflow forecasting capabilities, State-agency cooperators determined that "current conditions" were sufficient to meet their needs (B. Carr, West Virginia Department of Health and Human Resources, and D. Newell, West Virginia Department of Environmental Protection, written commun., 2023). Uncertainties in NWM streamflow forecasts greatly increase as the forecast range increases, with the short-range forecast having the least uncertainty. Therefore, the short-range NWM streamflow forecasts were used for the web tool.

The intent of the drought-vulnerability assessment, the near real-time PWS drought-awareness web tool, and this report is to increase understanding and awareness of drought risk for PWS in West Virginia. These products are intended to support planning and decision-making of water operators and government agencies in accordance with drought-response guidelines from WVDEM IS-6. The estimates and assumptions inherent in this approach are best used as a screening tool and would require in situ measurements and verification of withdrawal rates, water-supply storage, and streamflow for greatest accuracy. Users of the web tool should compare forecast conditions to actual conditions prior to taking any other action.

Summary

Surface-water withdrawals account for the majority (approximately 80 percent) of West Virginia's public water supply. Historic climate data and future climate modeling suggest localized and (or) seasonal droughts will continue to threaten water availability in the state, particularly in rural communities located in the headwaters of unregulated watersheds. Members of West Virginia's interagency drought task force lack key information about the potential impact of drought on public-water supplies to sufficiently prepare for and manage drought situations.

To assist water managers, a drought-vulnerability assessment was developed and conducted. Monthly water-withdrawal data obtained from the West Virginia Department of Environmental Protection's Large Quantity User program's regulatory database were used to calculate all-time, seasonal, and monthly 75th quantile withdrawal rates for 109 public water system (PWS) intakes withdrawing from surface waters in West Virginia. The drought-vulnerability assessment compares the all-time 75th quantile withdrawal rate to the 1-day, 10-year (1Q10) low-flow streamflow statistic calculated from U.S. Geological Survey tools and reports (U.S. Geological Survey, 2022; Wiley, 2008) for 71 of the 109 PWS with valid streamflow statistics (not below dams with regulated flow).

The drought-vulnerability assessment found 33 of 71 PWS with 75th quantile withdrawal rates greater than 100 percent of 1Q10 streamflow. Forty-one of 71 PWS have 75th quantile withdrawal rates more than 25 percent of 1Q10 streamflow, exceeding the State's drought-response threshold for water conservation. Forty-five of 71 PWS (63 percent) have 75th quantile withdrawals rates greater than 10 percent of 1Q10 streamflow, suggesting some level of ecological impairment during severe drought.

To support decision-making for emergency and water managers across West Virginia at the Federal, State, and local level, a near real-time drought-awareness web tool compares monthly 75th quantile withdrawal rates for 109 PWS to hourly streamflow forecasts from the National Water Model (Cosgrove and Gochis, 2018; Cosgrove and Klemmer, undated) and thresholds representing different levels of drought-related impacts from the West Virginia interagency drought plan and ecological-flow literature. Monthly PWS water withdrawal data for 2014–2020 and other ancillary site information used in this report and by the web tool are available from Kearns and Faunce (2023).

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Appendix 1. Seasonal Variation in Drought-Vulnerability Assessment of Public Water Systems in West Virginia

A drought-vulnerability assessment using the seasonal variability in 75th quantile withdrawal rate and 1Q10 low-flow streamflow statistics derived from Wiley and Atkins (2010) for 71 West Virginia public water systems with withdrawal intakes on surface waters without active flow regulation (table 1.1).

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Table 1.1. Seasonal variation in drought-vulnerability assessment of 71 selected West Virginia public water systems.

[Seasonal 1-day, 10-year hydrologically based flow (1Q10) in cubic-feet-per-second (ft³/s) computed using methods from Wiley and Atkins (2010). Withdrawal (WD) rate in ft³/s calculated as the 75th quantile of all reported in-season monthly withdrawals 2014–2020 (West Virginia Department of Environmental Protection, 2022). ID, identifier; WD/1Q10, withdrawal to 1-day, 10-year hydrologically based flow ratio; *, "divide by zero" error in 75th WD/1Q10 ratio]

Project identifier	Station name	Winter (January–March)			Spring (April–June)			Summer (July–September)			Fall (October–December)		
		1Q10 (ft³/s)	75th WD (ft³/s)	WD/1Q10 (percent)	1Q10 (ft³/s)	75th WD (ft³/s)	WD/1Q10 (percent)	1Q10 (ft³/s)	75th WD (ft³/s)	WD/1Q10 (percent)	1Q10 (ft³/s)	75th WD (ft³/s)	WD/1Q10 (percent)
ID001	Intake on Tygart Valley River 4352184	313	2.2408	1	115	1.9156	2	23.2	1.8548	8	26.8	1.8269	7
ID008	Intake on Middle Island Creek 15432570	7.82	0.4339	6	0.9	0.4092	46	0.05	0.4336	867	0.24	0.4304	179
ID010	Intake on South Branch Potomac River 8421608	117.23	1.5072	1	109.88	1.4485	1	52.15	1.4014	3	61.38	1.3592	2
ID012	Intake on Coal River 6929054	366.26	2.1971	1	189.65	1.9946	1	27.64	1.9797	7	44.25	1.9337	4
ID013	Intake On Coal River 6928118	165	0.8047	0	101	0.7858	1	20.5	0.8075	4	23.9	0.786	3
ID014	Intake on Cameron Reservoir 19454517	0.02	0.1328	664	0	0.1352	*	0	0.1723	*	0	0.1627	*
ID015	Intake on New Creek 14364804	5.02	1.5866	32	6.19	1.5942	26	1.39	1.4788	106	1.64	1.3542	82
ID018	Intake on Tug Fork 434540	160.72	0.7293	0	142.87	0.6061	0	44.43	0.5966	1	44.77	0.6953	2
ID019	Intake on Cobun Creek 3768582	1.5	8.978	599	0.15	6.2002	4,130	0	0.5021	*	0.04	4.0848	10,200
ID021	Intake on Rich Creek 6907585	1.25	0	0	1.2	0.0001	0	0.27	0.0007	0	0.41	0.0002	0
ID022	Intake on Panther Creek 4546776	1.96	0.6905	35	0.41	0.6334	154	0.09	0.6183	687	0.15	0.6398	427
ID023	Intake on Gauley River 4548030	275.45	1.5989	1	61.03	1.5166	2	13.2	1.5478	12	23.74	1.5077	6
ID024	Intake on Meadow River 4547418	63.97	0.4381	1	17.9	0.473	3	1.72	0.4935	29	2.33	0.4509	19
ID025	Intake on North Fork Blackwater River 3775885	0.2	0.1649	82	0.02	0.1576	788	0.01	0.1656	1,660	0.01	0.1553	1,550
ID027	Intake on Gauley River 4545684	29.1	0.5593	2	4.41	0.5483	12	0.96	0.5578	58	1.35	0.5259	39
ID028	Intake on North Fork Fishing Creek 15429208	3.52	0.1028	3	0.39	0.1021	26	0.01	0.1052	1,050	0.07	0.1053	150
ID029	Intake on Laurel Fork 6934372	8.55	1.0208	12	3.15	1.0102	32	0.69	1.0221	148	1	0.9549	95
ID030	Intake on J P Bailey Reservoir 6909475	0.03	0.3022	1,010	0.02	0.2678	1,340	0	0.2537	*	0.01	0.2704	2,700
ID031	Intake on Leatherbark Creek 12103894	1.05	0.0237	2	0.2	0.0221	11	0.05	0.0248	50	0.08	0.0239	30
ID032	Intake on Parker Hollow Reservoir 8433336	0.63	0.0581	9	0.45	0.0665	15	0.1	0.0666	67	0.16	0.0605	38
ID033	Intake on Shavers Lake 3777389	0.67	0.8681	130	0.07	0.4714	673	0.02	0.5342	2,670	0.03	0.7483	2,490
ID034	Intake on Tygart Valley River 4352996	55.27	0.5179	1	14.43	0.5325	4	0.99	0.4645	47	1.87	0.4338	23
ID037	Intake on Buckhannon River 4353190	67.51	3.4986	5	10.65	3.2667	31	1.91	3.4695	182	2.39	3.3327	139
ID040	Intake on Laurel Creek Reservoir 6909139	0.17	0.714	420	0.15	0.688	459	0.04	0.69	1,730	0.06	0.6225	1,040
ID041	Intake on North Fork Hughes River 19414131	5.33	0.9382	18	0.62	0.8669	140	0.01	0.9135	9,140	0.1	0.8305	831
ID043	Intake on Elk River 19323513	75.67	0.2079	0	18.07	0.2108	1	6.59	0.2116	3	10.54	0.1744	2
ID046	Intake on North Fork Cherry River 4546774	10.5	1.3329	13	1.76	1.1658	66	0.39	1.1471	294	0.58	1.1863	205
ID048	Intake on Buffalo Creek 6933832	1.85	0.575	31	0.5	0.5393	108	0.11	0.5394	490	0.18	0.5349	297
ID050	Intake on South Branch Potomac River 8420162	188	0.8105	0	190	0.7809	0	94	0.7398	1	98.5	0.6965	1

Table 1.1. Seasonal variation in drought-vulnerability assessment of 71 selected West Virginia public water systems.—Continued

[Seasonal 1-day, 10-year hydrologically based flow (1Q10) in cubic-feet-per-second (ft^3/s) computed using methods from Wiley and Atkins (2010). Withdrawal (WD) rate in ft^3/s calculated as the 75th quantile of all reported in-season monthly withdrawals 2014–2020 (West Virginia Department of Environmental Protection, 2022). ID, identifier; WD/1Q10, withdrawal to 1-day, 10-year hydrologically based flow ratio; *, “divide by zero” error in 75th WD/1Q10 ratio]

Project identifier	Station name	Winter (January–March)			Spring (April–June)			Summer (July–September)			Fall (October–December)		
		1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)
ID051	Intake on Buffalo Creek 19451633	16.3	0.3178	2	2.32	0.2781	12	0.14	0.2965	212	0.53	0.2635	50
ID053	Intake on Hurricane Creek 19315460	0.12	0.8709	726	0.01	0.9144	9,140	0	0.918	*	0	0.8489	*
ID054	Intake on Tygart Valley River 4352968	66.32	3.3901	5	10.44	2.9923	29	1.04	3.1444	303	2.43	3.0003	124
ID055	Intake on Tygart Valley River 4351508	109.62	0.4078	0	26.34	0.3955	2	3.15	0.3945	13	5.39	0.3899	7
ID056	Intake on South Fork South Branch Potomac River 8423472	8.73	0.0569	1	6.65	0.0608	1	2.35	0.0627	3	3.99	0.057	1
ID057	Intake on Greenbrier River 12107418	173.74	3.0905	2	103.81	3.1034	3	31.67	3.1349	10	41.1	2.955	7
ID058	Intake on Shavers Fork 3780353	81.41	0.3462	0	41.06	0.3356	1	10.07	0.3075	3	15.18	0.3098	2
ID061	Intake on Poplar Fork 19315530	0.26	7.6345	2,940	0.02	4.8175	24,100	0	1.3039	*	0	4.4508	*
ID062	Intake on Mill Creek 19442441	6.18	1.6693	27	0.72	1.6702	232	0.01	1.6655	16700	0.08	1.551	1,940
ID063	Intake on Ada Reservoir 6909509	0.04	0.9453	2,363	0.02	0.9151	4,580	0.01	1.2114	12100	0.01	1.0654	10,700
ID064	Intake on Horton Reservoir 6909515	0.03	1.9033	6,344	0.02	1.762	8,810	0	1.4656	*	0.01	1.113	11,100
ID065	Intake on Kee Reservoir 6909439	0.07	0.439	627	0.04	0.1116	279	0.01	0.2897	2900	0.02	0.2067	1,034
ID066	Intake on Dry Fork 3775187	126.25	0.1774	0	42.42	0.1806	0	9.69	0.18	2	16.25	0.1689	1
ID068	Intake on Bluestone Lake 6906551	795	4.0127	1	928	3.8175	0	178	3.9064	2	181	3.8029	2
ID069	Intake on Tug Fork 435286	97.37	0.5946	1	101.64	0.5824	1	36.83	0.6307	2	35.75	0.5504	2
ID071	Intake on Jones Run 3715724	0.81	0.3929	49	0.07	0.3353	479	0	0.3547	*	0.01	0.2795	2,800
ID074	Intake on Tug Fork 435154	107.23	3.141	3	107.06	2.8463	3	38.13	2.8004	7	37.27	2.8884	8
ID076	Intake on Glade Creek 6920946	2.31	11.8202	512	1.15	11.4844	999	0.26	11.9648	4,600	0.4	11.3585	2,840
ID077	Intake on Silcott Fork 19313070	0.1	0.2309	231	0.01	0.2209	2,210	0	0.2268	*	0	0.2036	*
ID078	Intake on Mill Run 14365556	0.66	0.2566	39	0.4	0.2514	63	0.07	0.2372	339	0.13	0.2299	177
ID079	Intake on Knapps Creek 12104384	15.6	0.3816	2	14.39	0.3173	2	3.77	0.2901	8	6.61	0.2894	4
ID080	Intake on Blackwater River 3774989	20.45	0.2063	1	9.21	0.2067	2	2.44	0.2206	9	3.51	0.2084	6
ID081	Intake on Cheat River 3775731	335.84	0.2147	0	155.43	0.2112	0	38.3	0.215	1	49.48	0.223	0
ID082	Intake on Tug Fork 433830	235.1	0.4272	0	202.59	0.4267	0	52	0.44	1	53.88	0.4248	1
ID083	Intake on Cheat River 3775677	364.37	1.1444	0	169.52	1.1738	1	40.71	1.1989	3	49.98	1.1267	2
ID085	Intake on Greenbrier River 12107522	221.2	0.666	0	138.93	0.64	0	45.13	0.6483	1	57.09	0.656	1
ID088	Intake on Tug Fork 434794	167	1.7936	1	135	1.718	1	27.2	1.7392	6	31.1	1.7075	5
ID090	Intake on Middle Island Creek 15431930	26.15	0.1455	1	3.42	0.1543	5	0.28	0.1591	57	0.47	0.1467	31

Table 1.1. Seasonal variation in drought-vulnerability assessment of 71 selected West Virginia public water systems.—Continued

[Seasonal 1-day, 10-year hydrologically based flow (1Q10) in cubic-feet-per-second (ft^3/s) computed using methods from Wiley and Atkins (2010). Withdrawal (WD) rate in ft^3/s calculated as the 75th quantile of all reported in-season monthly withdrawals 2014–2020 (West Virginia Department of Environmental Protection, 2022). ID, identifier; WD/1Q10, withdrawal to 1-day, 10-year hydrologically based flow ratio; *, “divide by zero” error in 75th WD/1Q10 ratio]

Project identifier	Station name	Winter (January–March)			Spring (April–June)			Summer (July–September)			Fall (October–December)		
		1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)	1Q10 (ft^3/s)	75th WD (ft^3/s)	WD/1Q10 (percent)
ID091	Intake on Shenandoah River 8445112	544.23	2.6067	0	571.29	2.7936	0	318.6	2.7251	1	338.55	2.6519	1
ID093	Intake on Gauley River 4545948	89.12	0.773	1	30.36	0.7848	3	4.23	0.7709	18	3.67	0.7283	20
ID094	Intake on Elk Run 5894528	1.7	0.3453	20	1.29	0.3614	28	0.35	0.3747	107	0.5	0.3278	66
ID095	Intake on Mill Creek 4352790	6.07	0.2983	5	0.63	0.2785	44	0.14	0.2809	201	0.23	0.2769	120
ID097	Intake on Guyandotte River 6934966	23.24	0.6957	3	21.2	0.6843	3	3.47	0.7204	21	4.53	0.7045	16
ID100	Intake on South Fork South Branch Potomac River 8419916	25.56	4.9796	19	24.24	4.974	21	9.32	5.2519	56	11.95	4.8014	40
ID102	Intake on South Branch Potomac River 8420282	141.58	0.0928	0	130.94	0.0245	0	57.15	0.083	0	69.33	0.0928	0
ID103	Intake on Fairfax Pond 3770326	0.23	0.4556	198	0.02	0.449	2,250	0	0.459	*	0	0.4781	*
ID104	Intake on Deckers Creek 3768762	0.57	0.4401	77	0.05	0.4536	907	0	0.4883	*	0.01	0.4198	4,200
ID105	Intake on Charles Fork 19419681	0.13	1.1152	858	0.01	1.1003	11,000	0	1.08	*	0	1.0801	*
ID108	Intake on Glenwood Lake 6909327	0.48	1.4481	302	0.38	1.411	371	0.09	1.5723	1750	0.14	1.5762	1,130
ID110	Intake on Patterson Creek 14368832	18.21	0.8346	5	13.57	0.8128	6	5.05	0.7681	15	6.51	0.7245	11
ID111	Intake on Greenbrier River 12107566	240.14	0.1746	0	159.68	0.1671	0	49.64	0.1742	0	60.52	0.1721	0
ID112	Intake on Greenbrier River 12105110	124	0.0554	0	70.2	0.0555	0	14.3	0.0534	0	17	0.0537	0

For more information, contact
Director, Virginia and West Virginia Water Science Center
U.S. Geological Survey
1730 East Parham Road
Richmond, VA 23228

Or visit our website at https://www.usgs.gov/centers/virginia-and-west-virginia-water-science-center.

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