Rating Stability, and Frequency and Magnitude of Shifts, for Streamgages in Virginia Through Water Year 2013

Scientific Investigations Report 2017–5137

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

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By Terence Messinger and Robert W. Burgholzer

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Acknowledgments

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

GAM	Generalized additive model
NWIS	National Water Information System
RMSE	Root-mean-square error
USGS	U.S. Geological Survey
VDEQ	Virginia Department of Environmental Quality

Rating Stability, and Frequency and Magnitude of Shifts, for Streamgages in Virginia Through Water Year 2013

Terence Messinger[1] and Robert W. Burgholzer[2]

Abstract

The U.S. Geological Survey, in cooperation with the Virginia Department of Environmental Quality, has quantified several measures of rating stability and the frequency and magnitude of changes to ratings through time for 174 real-time continuous streamgages active in Virginia as of September 30, 2013. Generalized additive models (GAMs) were fitted through all available flow measurements for all the streamgages in Virginia's real-time network as of September 30, 2013, with at least 20 flow measurements with positive flow values. For each measurement with a positive flow value, residuals from the GAM curve were calculated. Time series of these residuals were used to identify major changes to the control (the stream feature or features which control the relation between stage and flow); the measurements in the periods of equilibrium between major changes were assigned to rating families. Of the 127 rating families that were identified as being distinct at sites, documented explanations were found for 67 of them. The most common reasons for the control to change enough to warrant a new rating family are moving the streamgage (28 times), floods (26 times), and construction activities (13 times). Provisional flow data from any streamgage that has recently experienced a major flood, regardless of historical stability, are more uncertain than usual until post-flood evidence emerges that the rating is stable, or if the rating has changed, until it is known to be well defined.

A direct comparison between provisional flow data (those data originally displayed on the web in near-real time) and flow data approved for publication following subsequent flow measurements and review could not be made because provisional flow data have not been archived. As a substitute, alternative flow (AltFlow) tables were constructed for periods with complete records of shifts and ratings. Alternate flows consist of Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value, and Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value.

Several metrics that summarize AltFlow tables were computed and evaluated; particular importance was given to how well the metrics agreed with the descriptive stability class developed from interviews with hydrographers. Of these stability metrics, at least four were determined to be meaningful and to represent different aspects of control stability that might be relevant to water managers: total root mean square error between log-transformed Q_{prev} and Q_{same}, percentage of days when the difference between Q_{prev} and Q_{same} is greater than (>) Q_{same}, the sum of absolute AltFlow error divided by total flow, and percentage of days with zero difference between Q_{prev} and Q_{same}.

Three other meaningful metrics of control stability or provisional flow-data quality were computed: R^2 (coefficient of determination) of GAMs from the flow measurements, percentage of total estimated days, and percentage of estimated days in the winter. Correlations among metrics varied, indicating they responded to different aspects of control stability. Relations among the various stability metrics and quantitative basin and site characteristics were weak. Although quantitative relations between stability metrics and basin and site characteristics were all weak, some common patterns still emerged. Controls and ratings on large streams [>500-square mile (mi^2) drainage area] and at high elevations (>1,000 feet) were more likely to be stable than controls and ratings on small streams (less than (<) 100-mi^2 drainage area) and at low elevations (<500 feet). There were exceptions to both generalizations, and streamgages that were intermediate in both characteristics varied widely in stability.

Typical timing of record computation changed during water years 1991–2013. From 1991 through 2001, the median number of days between the start date of the shift and the date it was created fluctuated between about 240 and about 300 days and decreased by about 4 months from 2001 to 2002. Only in 2012 and 2013 did one-half of the shifts have a delay of about 60 days between start date and final modification.

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[1]U.S. Geological Survey

[2]Virginia Department of Environmental Quality

Introduction

The U.S. Geological Survey (USGS) began posting flow data on the internet in near real time in 1994, during a time when streamgages equipped with satellite telemetry increased from 14 percent in 1983 to 64 percent in 1997 (U.S. Geological Survey, 1998). Since then, many emergency responders, water managers, anglers, boaters, and others increasingly have come to rely on the accuracy of real-time flow data to make decisions that affect the safety of life and property.

Continuous flow typically is not measured directly. Instead, it is computed from stage measurements using a "rating curve," or a curve fitted through points representing the direct measurements of stage and flow that are made during periodic streamgage inspections. At all streamgages, rating curves change through time as a result of changes to "controls," the bed or channel features that control the water level in the gaging pool. The gaging pool is the pool of water where stage, or gage height, is measured. The stability of controls varies greatly among streamgages. Changes to controls can be determined only by inspection or measurement, can be quantified only by measurement, and are the reason periodic flow measurements are made. Reliability of real-time flow data depends primarily on the stability of the control. Other factors are also important, however, notably how prone the streamgage intake or orifice is to sediment deposition. Changes to controls that require several flow measurements to define are common.

The USGS, in cooperation with the Virginia Department of Environmental Quality (VDEQ), has quantified several measures of rating stability and the frequency and magnitude of changes to ratings through time for 174 real-time continuous streamgages active in Virginia as of October 2013. This study is intended to help water managers understand how much confidence may be placed in preliminary flow data collected at these streamgages.

Purpose and Scope

The purpose of this report is to describe the steps taken to quantify the stability of stage-flow ratings for streams in Virginia, to help evaluate the reliability of the ratings to provide real-time flow data. Two different analytical approaches are employed. (1) Flow measurements are compared to long-term average ratings by flow, date, and day-of-year, and (2) mean daily flows for water years[1] 1991–2013 are compared to flows that would have been computed from the rating in effect when the previous flow measurement was made. Stability metrics including root mean square error (RMSE), percent error, and days with zero differences are computed for these two sets of flows and are presented in total and by month and flow

percentile. Efforts are made to correlate the stability metrics with stream and basin characteristics.

Description of the Virginia Streamgage Network

One hundred seventy-four real-time streamgages were active in Virginia as of September 30, 2013, the end of the study period (table 1, fig. 1). At that time, streamgages in Virginia were operated by three field offices, two USGS offices in Richmond and Marion, and a VDEQ office in Charlottesville. The VDEQ and, before it, the Virginia Water-Control Board, has been operating streamgages according to USGS specifications and protocols for decades. Data collected by both organizations are treated as interchangeable and as meeting the same quality standards. Streamgages are traded between the two organizations on an irregular basis related partly to operational considerations, such as funding and staffing, and to differences in the missions of the two agencies. No distinction is made between data collected by the two organizations in interpretive products, such as peak-flow and low-flow regression equations. The USGS opened a new field office in Leetown, West Virginia, in 2014, after the end of the study period.

Virginia's environmental setting has been described in detail previously (Hayes, 1989; Nelms and others, 1997; Nelms and others, 2003). Aspects of the environmental setting discussed in those reports that are relevant to this study include physiography, elevation, land use, and interactions among them.

Streamgaging Operations

The USGS collects flow data using a clearly defined set of field and office procedures. Although procedures have changed through time, they have been documented since the 1900s (Murphy and others, 1904; Corbett and others, 1943; Rantz and others, 1982; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010). Development of stage-flow ratings and shifts (temporary ratings) that reflect controls and changes to them are a key part of the flow data collection and computation procedure.

General Field and Office Procedures

Streamgaging field procedures have been developed to enable the USGS to collect complete and accurate stage data and maintain the stage-flow ratings, including documenting changes to it through time. This requires that hydrographers, the technicians and scientists who collect and compute flow data, make flow measurements and maintain streamgages at regular intervals.

Stage is recorded continuously using a variety of technologies. The USGS in Virginia measures stage using a variety of sensors, including stilling wells with float-driven recorders,

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[1]A water year is the 12-month period from October 1 to September 30. It is designated by the year in which it ends.
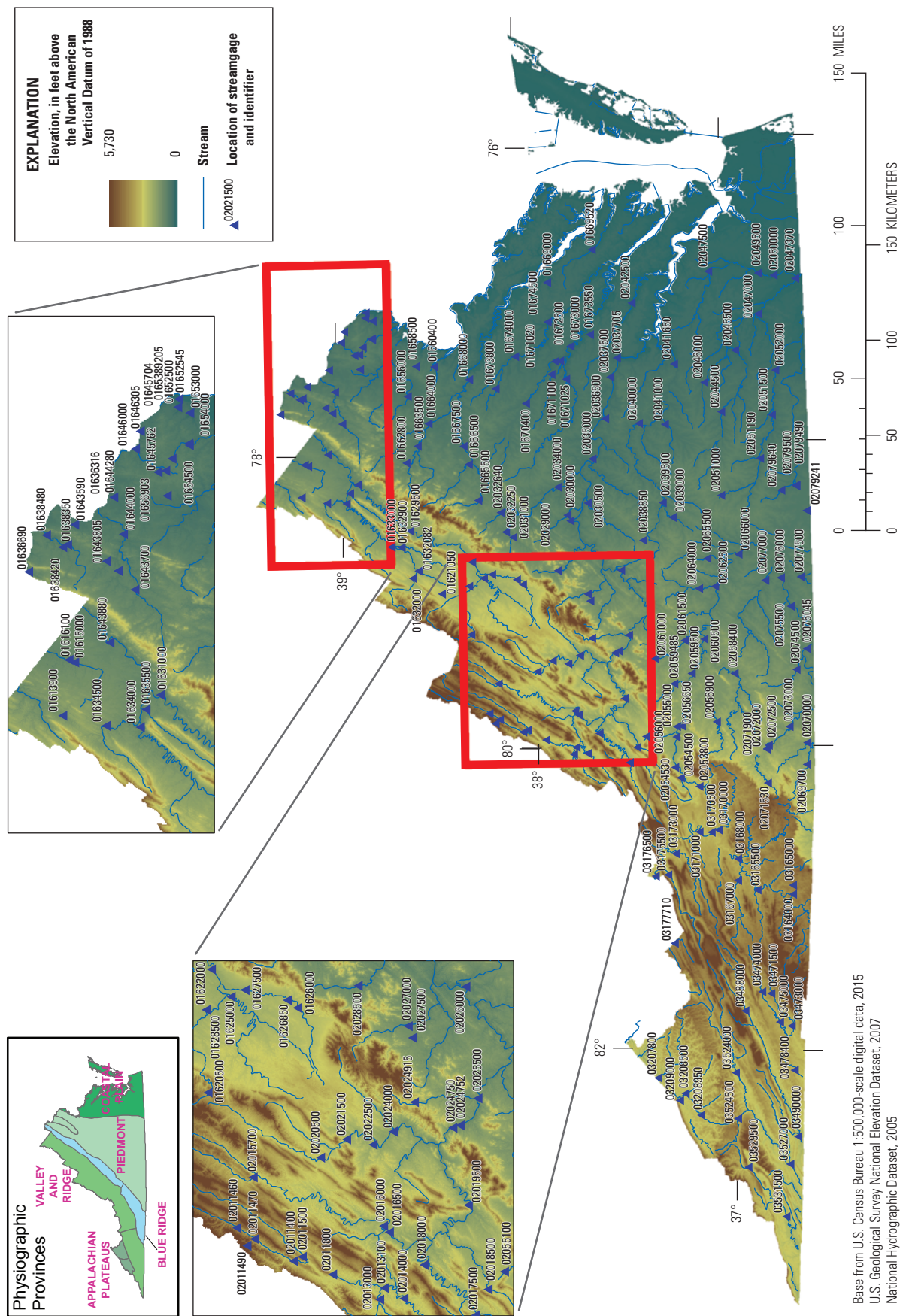
Figure 1. Elevation, physiographic provinces, streams, and streamgages active as of September 30, 2013, in Virginia.

Base from U.S. Census Bureau 1:500,000-scale digital data, 2015
U.S. Geological Survey National Elevation Dataset, 2007
National Hydrographic Dataset, 2005

Table 1.   Virginia streamgage numbers, names, drainage areas, locations, and elevations.

[mi², square miles; dd, decimal degrees; ft, feet; —, undefined; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Drainage area (mi²)	Latitude (dd)	Longitude (dd)	Elevation of gage (ft)
01613900	Hogue Creek near Hayfield, VA	15.9	39.2145	-78.2881	669
01615000	Opequon Creek near Berryville, VA	58.2	39.1747	-78.0783	503
01616100	Dry Marsh Run near Berryville, VA	11.0	39.1926	-78.0686	501
01620500	North River near Stokesville, VA	17.3	38.335	-79.2392	2,051
01621050	Muddy Creek at Mount Clinton, VA	14.3	38.4868	-78.9603	1,360
01622000	North River near Burketown, VA	376	38.3404	-78.9136	1,103
01625000	Middle River near Grottoes, VA	373	38.2618	-78.8620	1,062
01626000	South River near Waynesboro, VA	127	38.0576	-78.9081	1,296
01626850	South River near Dooms, VA	148	38.0887	-78.8770	1,247
01627500	South River at Harriston, VA	212	38.2187	-78.8367	1,130
01628500	South Fork Shenandoah River near Lynnwood, VA	1,079	38.3226	-78.7547	1,002
01629500	South Fork Shenandoah River near Luray, VA	1,372	38.6462	-78.5347	722
01631000	South Fork Shenandoah River at Front Royal, VA	1,634	38.9140	-78.2108	469
01632000	North Fork Shenandoah River at Cootes Store, VA	210	38.6371	-78.8528	1,051
01632082	Linville Creek at Broadway, VA	45.7	38.6068	-78.8034	1,030
01632900	Smith Creek near New Market, VA	93.6	38.6935	-78.6428	881
01633000	North Fork Shenandoah River at Mount Jackson, VA	508	38.7457	-78.6389	839
01634000	North Fork Shenandoah River near Strasburg, VA	770	38.9768	-78.3361	493
01634500	Cedar Creek near Winchester, VA	102	39.0812	-78.3294	647
01635500	Passage Creek near Buckton, VA	86.5	38.9582	-78.2667	525
01636316	Spout Run at Rt 621 near Millwood, VA	21.4	39.0670	-78.0038	430
01636690	Piney Run near Lovettsville, VA	13.5	39.3108	-77.7185	397
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	31.6	39.1911	-77.6154	336
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	23.1	39.205	-77.6239	325
01638480	Catoctin Creek at Taylorstown, VA	89.5	39.2551	-77.5764	247
01643590	Limestone Branch near Leesburg, VA	7.88	39.1676	-77.5359	220
01643700	Goose Creek near Middleburg, VA	122	38.9865	-77.7967	327
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	38.1	39.0723	-77.6839	295
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	47.2	39.0377	-77.7223	307
01644000	Goose Creek near Leesburg, VA	332	39.0196	-77.5775	249
01644280	Broad Run near Leesburg, VA	76.1	39.0464	-77.4324	194
01645704	Difficult Run above Fox Lake near Fairfax, VA	5.49	38.8847	-77.3324	296
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	2.71	38.9089	-77.3383	274
01646000	Difficult Run near Great Falls, VA	57.8	38.9759	-77.2458	151
01646305	Dead Run at Whann Avenue near Mclean, VA	2.05	38.9598	-77.1757	178
01652500	Fourmile Run at Alexandria, VA	12.6	38.8433	-77.0859	29
01653000	Cameron Run at Alexandria, VA	33.9	38.8065	-77.1097	32
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	3.99	38.8662	-77.2864	296
01654000	Accotink Creek near Annandale, VA	23.9	38.8129	-77.2283	191
01656000	Cedar Run near Catlett, VA	93.4	38.6368	-77.6250	199
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	4.20	38.8824	-77.4319	257
01658500	South Fork Quantico Creek near Independent Hill, VA	7.62	38.5873	-77.4286	238
01660400	Aquia Creek near Garrisonville, VA	35.0	38.4904	-77.4336	120
01662800	Battle Run near Laurel Mills, VA	25.8	38.6557	-78.0739	375
01663500	Hazel River at Rixeyville, VA	285	38.5918	-77.9650	288

Table 1. Virginia streamgage numbers, names, drainage areas, locations, and elevations.—Continued

[mi^2, square miles; dd, decimal degrees; ft, feet; —, undefined; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Drainage area (mi^2)	Latitude (dd)	Longitude (dd)	Elevation of gage (ft)
01664000	Rappahannock River at Remington, VA	619	38.5307	-77.8136	252
01665500	Rapidan River near Ruckersville, VA	115	38.2807	-78.3400	439
01666500	Robinson River near Locust Dale, VA	179	38.3251	-78.0956	284
01667500	Rapidan River near Culpeper, VA	468	38.3504	-77.9750	241
01668000	Rappahannock River near Fredericksburg, VA	1,595	38.3085	-77.5292	70
01669000	Piscataway Creek near Tappahannock, VA	27.9	37.8771	-76.9005	1
01669520	Dragon Swamp at Mascot, VA	109	37.6338	-76.6963	22
01670400	North Anna River near Partlow, VA	342	38.0129	-77.7011	167
01671020	North Anna River at Hart Corner near Doswell, VA	462	37.8501	-77.4278	43
01671025	North Anna River above Little River near Doswell, VA	467	37.8257	-77.4261	35
01671100	Little River near Doswell, VA	107	37.8726	-77.5130	132
01672500	South Anna River near Ashland, VA	395	37.7968	-77.5489	83
01673000	Pamunkey River near Hanover, VA	1,078	37.7676	-77.3322	14
01673550	Totopotomoy Creek near Studley, VA	25.5	37.6626	-77.2578	38
01673800	Po River near Spotsylvania, VA	77.6	38.1715	-77.5947	184
01674000	Mattaponi River near Bowling Green, VA	256	38.0618	-77.3858	84
01674500	Mattaponi River near Beulahville, VA	603	37.8839	-77.1653	11
02011400	Jackson River near Bacova, VA	157	38.0423	-79.8814	1,639
02011460	Back Creek near Sunrise, VA	60.9	38.2454	-79.7687	2,200
02011470	Back Creek at Sunrise, VA	75.6	38.1904	-79.8117	1,968
02011490	Little Back Creek near Sunrise, VA	4.90	38.2146	-79.8376	2,638
02011500	Back Creek near Mountain Grove, VA	134	38.0696	-79.8970	1,701
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	345	37.9485	-79.9492	1,400
02013000	Dunlap Creek near Covington, VA	162	37.8029	-80.0470	1,294
02013100	Jackson River below Dunlap Creek at Covington, VA	612	37.7887	-80.0006	1,206
02014000	Potts Creek near Covington, VA	153	37.7290	-80.0423	1,273
02015700	Bullpasture River at Williamsville, VA	110	38.1954	-79.5703	1,610
02016000	Cowpasture River near Clifton Forge, VA	461	37.7918	-79.7595	1,007
02016500	James River at Lick Run, VA	1,371	37.7737	-79.7845	978
02017500	Johns Creek at New Castle, VA	105	37.5062	-80.1067	1,254
02018000	Craig Creek at Parr, VA	329	37.6660	-79.9114	992
02018500	Catawba Creek near Catawba, VA	34.3	37.4682	-80.0053	1,300
02019500	James River at Buchanan, VA	2,073	37.5307	-79.6789	802
02020500	Calfpasture River above Mill Creek at Goshen, VA	141	37.9879	-79.4937	1,383
02021500	Maury River at Rockbridge Baths, VA	329	37.9074	-79.4220	1,100
02022500	Kerrs Creek near Lexington, VA	35.1	37.8257	-79.4431	980
02024000	Maury River near Buena Vista, VA	647	37.7626	-79.3914	846
02024752	James River at Blue Ridge Pkwy near Big Island, VA	3,076	37.5554	-79.3673	601
02024915	Pedlar River at Forest Road near Buena Vista, VA	27.1	37.6975	-79.2783	1,135
02025500	James River at Holcomb Rock, VA	3,256	37.5013	-79.2625	548
02026000	James River at Bent Creek, VA	3,649	37.5363	-78.8295	380
02027000	Tye River near Lovingston, VA	93.0	37.7154	-78.9817	575
02027500	Piney River at Piney River, VA	47.7	37.7024	-79.0275	632
02028500	Rockfish River near Greenfield, VA	94.8	37.8696	-78.8234	532
02029000	James River at Scottsville, VA	4,581	37.7974	-78.4914	252

Table 1.   Virginia streamgage numbers, names, drainage areas, locations, and elevations.—Continued

[mi², square miles; dd, decimal degrees; ft, feet; —, undefined; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Drainage area (mi²)	Latitude (dd)	Longitude (dd)	Elevation of gage (ft)
02030000	Hardware River below Briery Run near Scottsville, VA	116	37.8126	-78.4553	295
02030500	Slate River near Arvonia, VA	226	37.7029	-78.3775	239
02031000	Mechums River near White Hall, VA	95.3	38.1026	-78.5928	430
02032250	Moormans River near Free Union, VA	77.0	38.1407	-78.5558	403
02032640	North Fork Rivanna River near Earlysville, VA	108	38.1635	-78.4247	365
02034000	Rivanna River at Palmyra, VA	663	37.8579	-78.2658	210
02035000	James River at Cartersville, VA	6,252	37.6710	-78.0858	164
02036500	Fine Creek at Fine Creek Mills, VA	22.4	37.5979	-77.8197	157
02037000	James River And Kanawha Canal near Richmond, VA	—	37.5646	-77.5742	106
02037500	James River near Richmond, VA	6,753	37.5632	-77.5469	99
02038850	Holiday Creek near Andersonville, VA	8.54	37.4154	-78.6358	473
02039000	Buffalo Creek near Hampden Sydney, VA	69.6	37.2571	-78.4864	339
02039500	Appomattox River at Farmville, VA	302	37.3071	-78.3886	281
02040000	Appomattox River at Mattoax, VA	725	37.4215	-77.8589	175
02040892	Appomattox River at Route 602 near Mannboro, VA	942	37.3181	-77.8017	161
02041000	Deep Creek near Mannboro, VA	158	37.2832	-77.8697	177
02041650	Appomattox River at Matoaca, VA	1,342	37.2252	-77.4753	68
02042500	Chickahominy River near Providence Forge, VA	251	37.4363	-77.0608	5
02044500	Nottoway River near Rawlings, VA	317	36.9835	-77.7997	185
02045500	Nottoway River near Stony Creek, VA	577	36.9001	-77.3997	58
02046000	Stony Creek near Dinwiddie, VA	113	37.0671	-77.6025	130
02047000	Nottoway River near Sebrell, VA	1,441	36.7704	-77.1661	5
02047500	Blackwater River near Dendron, VA	290	37.0251	-76.8747	0
02049500	Blackwater River near Franklin, VA	613	36.7626	-76.8983	0
02051000	North Meherrin River near Lunenburg, VA	56.0	36.9974	-78.3497	334
02051500	Meherrin River near Lawrenceville, VA	552	36.7168	-77.8317	137
02052000	Meherrin River at Emporia, VA	744	36.6901	-77.5405	67
02053800	South Fork Roanoke River near Shawsville, VA	109	37.1401	-80.2664	1,362
02054500	Roanoke River at Lafayette, VA	254	37.2365	-80.2092	1,174
02054530	Roanoke River at Glenvar, VA	281	37.2679	-80.1395	1,100
02055000	Roanoke River at Roanoke, VA	384	37.2585	-79.9386	906
02055100	Tinker Creek near Daleville, VA	11.7	37.4176	-79.9353	1,212
02056000	Roanoke River at Niagara, VA	509	37.2551	-79.8714	820
02056650	Back Creek near Dundee, VA	55.8	37.2276	-79.8681	823
02056900	Blackwater River near Rocky Mount, VA	115	37.0451	-79.8442	876
02058400	Pigg River near Sandy Level, VA	351	36.9460	-79.5248	616
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	125	37.2664	-79.5878	704
02059500	Goose Creek near Huddleston, VA	188	37.1732	-79.5203	593
02060500	Roanoke River at Altavista, VA	1,782	37.1046	-79.2953	502
02061000	Big Otter River near Bedford, VA	114	37.3640	-79.4192	670
02061500	Big Otter River near Evington, VA	315	37.2085	-79.3036	544
02062500	Roanoke (Staunton) River at Brookneal, VA	2,404	37.0394	-78.9457	351
02064000	Falling River near Naruna, VA	165	37.1268	-78.9597	412
02065500	Cub Creek at Phenix, VA	97.6	37.0793	-78.7636	370
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	36.9151	-78.7408	308

Table 1. Virginia streamgage numbers, names, drainage areas, locations, and elevations.—Continued

[mi², square miles; dd, decimal degrees; ft, feet; —, undefined; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Drainage area (mi²)	Latitude (dd)	Longitude (dd)	Elevation of gage (ft)
02069700	South Mayo River near Nettleridge, VA	85.5	36.5710	-80.1295	872
02070000	North Mayo River near Spencer, VA	108	36.5682	-79.9873	731
02071530	Smith River at Smith Riv Church near Woolwine, VA	26.3	36.7785	-80.2492	1,210
02072000	Smith River near Philpott, VA	215	36.7807	-80.0248	804
02072500	Smith River at Bassett, VA	259	36.7701	-80.0009	752
02073000	Smith River at Martinsville, VA	379	36.6612	-79.8806	657
02074500	Sandy River near Danville, VA	111	36.6196	-79.5042	460
02075045	Dan River at Stp near Danville, VA	2,116	36.5626	-79.3697	365
02075500	Dan River at Paces, VA	2,587	36.6424	-79.0895	322
02077000	Banister River at Halifax, VA	547	36.7765	-78.9158	316
02077500	Hyco River near Denniston, VA	288	36.5879	-78.8986	315
02079640	Allen Creek near Boydton, VA	53.5	36.6796	-78.3267	217
03164000	New River near Galax, VA	1,141	36.6473	-80.9790	2,208
03165000	Chestnut Creek at Galax, VA	39.4	36.6460	-80.9192	2,344
03165500	New River at Ivanhoe, VA	1,350	36.8348	-80.9526	1,942
03167000	Reed Creek at Grahams Forge, VA	258	36.9390	-80.8873	1,925
03168000	New River at Allisonia, VA	2,212	36.9376	-80.7456	1,848
03170000	Little River at Graysontown, VA	309	37.0376	-80.5567	1,816
03171000	New River at Radford, VA	2,767	37.1418	-80.5692	1,712
03173000	Walker Creek at Bane, VA	299	37.2682	-80.7095	1,666
03175500	Wolf Creek near Narrows, VA	223	37.3057	-80.8498	1,584
03176500	New River at Glen Lyn, VA	3,783	37.3729	-80.8606	1,490
03177710	Bluestone River at Falls Mills, VA	44.3	37.2715	-81.3048	2,310
03207800	Levisa Fork at Big Rock, VA	297	37.3537	-82.1957	866
03208500	Russell Fork at Haysi, VA	286	37.2071	-82.2957	1,238
03208950	Cranes Nest River near Clintwood, VA	66.5	37.1240	-82.4388	1,440
03209000	Pound River below Flannagan Dam, near Haysi, VA	221	37.2371	-82.3432	1,200
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	76.6	36.7604	-81.6312	2,107
03473000	South Fork Holston River near Damascus, VA	303	36.6518	-81.8440	1,792
03474000	Middle Fork Holston River at Seven Mile Ford, VA	132	36.8073	-81.6221	1,960
03475000	Middle Fork Holston River near Meadowview, VA	206	36.7132	-81.8187	1,820
03478400	Beaver Creek at Bristol, VA	26.9	36.6318	-82.1337	1,781
03488000	North Fork Holston River near Saltville, VA	221	36.8968	-81.7462	1,704
03490000	North Fork Holston River near Gate City, VA	671	36.6087	-82.5679	1,198
03524000	Clinch River at Cleveland, VA	533	36.9448	-82.1549	1,925
03524500	Guest River at Coeburn, VA	87.2	36.9293	-82.4563	1,926
03527000	Clinch River at Speers Ferry, VA	1,123	36.6487	-82.7504	1,196
03529500	Powell River at Big Stone Gap, VA	112	36.8690	-82.7754	1,458
03531500	Powell River near Jonesville, VA	319	36.6620	-83.0949	1,259

bubble gages with submersible and non-submersible pressure transducers, and non-contact radar and acoustic sensors (Sauer and Turnipseed, 2010). When installed and maintained properly, both stage measurement systems can be used to collect stage data accurate to within 0.01 foot or 0.2 percent of the effective stage, whichever is greater. In general, a bubble gage and transducer may be installed more quickly and for a lower cost than a stilling well, but a bubble gage and transducer may need to be replaced more frequently during the lifetime of the streamgage.

Flow measurements are made to develop ratings at new sites and to document changes to them once established. Routine trips are frequent enough to characterize the stage-flow relation for low, medium, and moderately high flows. Extra visits are made to measure floods, which are infrequent and are of particular interest to major national institutional stakeholders. Additionally, the relation between flood stage and flow typically remains stable for years or decades. Water velocity is measured with either a Price-type vertical axis mechanical current meter or a hydroacoustic Doppler velocimeter, a class of instrument that includes Acoustic Doppler Current Profilers. In wadeable streams, either type of meter may be deployed from a wading rod, which is also used to sound depth. At nonwadeable flows, hydroacoustic velocimeters are deployed on a custom-made boat that is towed across the river from a bridge, cableway, or boat, and depth is measured using a sonic sounder incorporated into the meter. If a mechanical meter is used, it is deployed with sounding weights from a cable lowered from a bridge, cableway, or boat, and the depth is read from a dial attached to the cable reel.

The principal field tasks for streamgaging are measuring flow and maintaining stage sensors and related equipment and structures. Some tasks are done about annually, such as differential leveling from gage features to benchmarks to ensure that instruments or bubble gage orifices have remained physically stable and therefore are capable of recording accurate stage data. Other maintenance tasks need to be done more frequently; the necessary frequency varies according to site conditions, such as sediment load and deposition patterns. A routine site visit includes checking the recording gage against a non-recording reference gage, flushing intakes at stilling wells, repairing or replacing any equipment that has malfunctioned, and a control inspection.

Documentation of control inspections provides a record of changes to the control through time. This documentation is critically important for interpreting rating changes. Common changes to controls include scour and fill during rises in flow, growth and death of macrophytes and algae, and accumulation and removal of leaves or large woody debris. Less common changes that may be large in magnitude include those caused by humans or animals placing material on or removing material from the control; some of the largest rating changes at low flow result from dams built by beavers or swimmers. Several of these types of changes are clearly temporary. Changes to a control related to scour and fill may be either short term or long term, and the judgment about how long to expect such a change to remain typically is made in light of previous experience with the site and magnitude of the change.

Flow Data Computation

Flow data computation is complex and includes several steps that are done manually and involve data interpretation on the part of the hydrographer. Quality assurance of stage data is necessary but usually simple. When it is not simple, the aspects of the stage record that require the most interpretation involve records affected by sediment deposition on intakes or orifices, equipment malfunctions, or errors resulting from the movement of stage sensors as discovered through differential leveling. Stage sensors move rarely, such as during a major flood, but when they do, correcting the record requires extensive work. Equipment is much more reliable than it was historically but might still malfunction at a few sites operated by any specific field office during a year. In contrast, sediment deposition is common and unavoidable in some streams, particularly low-gradient streams where the streambed includes substantial amounts of clay, silt, and sand. Correcting stage records affected by deposition requires extensive interpretation.

Development and maintenance of the rating curve is fully interpretive. Rating curves are empirical, and curve fitting is done graphically. Most streamgages have simple controls, for which stage is a simple function of flow; however, for some streamgages, control is a function of rate of variable backwater, tide, or some other characteristic. At streamgages with simple controls, the rating curve is a graphical depiction of the stage-flow relation for a specific hydraulic control, typically a natural feature such as a channel constriction, change in streambed slope, or the aggregate characteristics of channel slope and roughness. Where the feature in question is a weir or a bedrock ledge, or is formed from bedrock and large boulders, the control typically changes infrequently, and office work related to the rating may be straightforward. Where the feature is formed from small boulders, cobbles, sand, fine materials, or a mixture of substrates, the control may change frequently and require extensive office work to analyze the stage-flow relation.

Each measurement is evaluated carefully, first in the field, where it is initially plotted on the rating curve, and later in light of successive measurements. Measurements that plot off the curve by more than the expected percentage require a new rating, a shift, or an explanation for the error of the measurement. A shift is a temporary rating curve, which is typically a modification of the base rating curve for part of its range in stage. The decision on whether to respond to a change to a control by using a shift or a new rating involves determining when the control changed, the nature of the change, and how long the change lasted or is expected to last. A new base rating is essentially impossible to develop on the basis of a single measurement, even in cases such as obvious large changes to

controls following major floods. However, a rating may be developed as the necessary measurements become available, and when complete, the rating can be backdated to the time of the actual change to the control. In this case, provisional data displayed on the web will be processed using a series of shifts, but the final "approved data" will be processed using the final rating. Often, the provisional data are corrected during review. The office procedures the USGS has historically used for computing flow data include several steps of review, any of which may result in corrections. Substantial changes to initial data are common, including to provisional data that previously have been posted online and used by the public.

The development of shifts and ratings are discussed in an internal document, the station analysis, which is prepared for each streamgage every year and archived permanently. The station analysis comprehensively details changes in stage datums; the adjustment and correction of stage data, including corrections applied as a result of documented sensor drift; the nature and condition of the channel controls, including changes in the location, shape, composition, and roughness of the control; the shape and historical stability of the resulting ratings; the number, quality, and range of the flow measurements and their relation to the rating in terms of coverage of stage and time; and the detection of shifts and the adjustment of them to account for control changes. The station analysis also documents efforts to compare the resulting flow records to flow records collected for other locations on the same or nearby streams, as well as to other hydrologic or meteorological information (such as rainfall or temperature records). Lastly, the station analysis documents the subjective quality assessment of the hydrographer who computes the record and prepares the station analysis.

The station analysis and all of the elements of the flow record are reviewed by a colleague hydrographer, the office chief or supervisor, and often one or more hydrographers from another office or other technical specialists. The Virginia Water Science Center of the USGS also runs various computer scripts that scan the record for outliers and inconsistencies, the rating and shifts for unusual or hydraulically unsound shapes and changes. All of these steps contribute to the production of a reliable and defensible "approved" flow record, but few of the steps were applied prior to the automatic posting of "provisional" record.

To help guide individual hydrographers and to instill more consistency in local practices, the USGS requires each Water Science Center to develop a single, comprehensive quality-assurance plan for surface-water activities within the center, including its streamgaging operations. The document provides guidance on the need for measurements, guidance on parameters for measurement frequency and range, and instructions about which control, measurement, and instrumentation factors to consider when conducting fieldwork or processing records, including rating development and shift applications. The document also establishes requirements for training of hydrographers and the review of their work.

The quality of the flow record is assessed and recorded in Water Year Summaries, which have replaced Site Data Sheets, which had previously replaced Annual Water-Data Reports (U.S. Geological Survey, 2016a). The assessment reflects the judgment of hydrographers from the station analysis. These qualitative assessments are among the information that USGS publishes to the Water Year Summaries, but the assessments are not captured in the National Water Information System or related electronic databases. Therefore, the assessments are difficult to incorporate in quantification studies.

Although the USGS has made standardizing record processing a priority, the processing has retained elements of a craft. Individual judgment is part of the process. Different analysts may achieve the same results using slightly different methods. For the purposes of this study, these differences matter because, by design, criteria for developing a shift overlap with criteria for developing a new rating. A shift is to be applied when in the hydrographer's judgment the rating change is temporary, in contrast to a new rating, which is to be developed when a change to a control is permanent (or has reached equilibrium). In practice, hydrographers make judgments differently about whether a measured change is temporary or permanent. Some will develop a new rating as soon as enough measurements have been made to define the change, whereas others will apply a shift for several years, adjusting it as needed, to see whether the control changes back. Some hydrographers might apply and adjust shifts for years or even decades through a series of bed changes without changing the base rating. These analytical differences make little if any difference to the published flow data but complicate efforts to use the number and frequency of rating changes to compare stability among sites and through time.

The USGS has implemented "continuous records processing," a procedure in which data are processed immediately upon the return of hydrographers to the office from a field trip. In 2014, the USGS Office of Surface Water (OSW) issued Technical Memorandum 2014–08, which calls for all USGS Water Science Centers to correct time-series stage and flow data and enter flow measurements into the National Water Information System Web (NWIS-Web) database within 2 business days of a field measurement. Computed real-time data on NWIS-Web that do not match the flow measurement within its rated accuracy are to be corrected or removed from public display (Robert Mason, U.S. Geological Survey, written commun., July 14, 2014, https://hydroacoustics.usgs.gov/memos/OSW2014-08.pdf). Even after continuous records processing has been fully implemented, however, uncertainty will remain as to the accuracy of provisional flow data. The accuracy of provisional flow data depends on several factors, including quality and promptness of field and office work, the quality of the stage record, and the stability of the rating.

Hydrographers are forced to make judgments about the timing of rating changes and shifts. When the change in rating can be associated plausibly with a distinct rise in flow, most hydrographers attempt to start the new rating to coincide with

peak flow. When this is not practical, ratings will begin on convenient but arbitrary dates. Some hydrographers prefer to change base ratings relatively frequently and attempt to associate the start time with a hydrologic event. Others will change base ratings at convenient times and use shifts before and after the base-rating change to make a smooth transition. A great deal of care is taken to look for a plausible event for the beginning of shifts, regardless of the approach used for the timing for base-rating changes. A scour shift typically begins while flow rises, and a fill shift begins while flow recedes. This practice is based on an extensive body of empirical evidence from flow measurements made across rises in flow at many streamgages (Rantz and others, 1982).

Monthly field measurements were standard from the beginning of continuously recorded stage until telemetry or satellite data transmissions became widely used in the 1980s. At that time, adoption of the new technology, which enabled hydrographers to know whether stage was being recorded, coincided with increased budgetary pressures. The USGS did a series of studies in most states during the 1980s intended to optimize network design. The studies were modeled after work done in the Lower Colorado River Basin (U.S. Geological Survey, 1998; Moss and Gilroy, 1980). Primary considerations were cost effectiveness, minimizing lost record, and characterizing rating changes. An algorithm was developed that allowed the tradeoffs between various options to be quantified as their contributions to the standard error of mean annual flow. This algorithm was applied on a state-by-state basis, and the results were aggregated nationally. This led to the determination that for most states, the optimal tradeoff between cost and accuracy for a typical streamgage was a frequency of 6–8 site visits per year. More measurements are made for streamgages where beds are extremely unstable, such as those with sand beds, or at locations where consequences of error are great, such as the Colorado River at the United States–Mexico border (Wahl and others, 1995; Anning, 2001).

Ratings and Shifts for Streamgages in Virginia through 2013

Availability of ratings and shifts varied by streamgage, largely because archival methods varied by field office and immediate operational needs (tables 2 and 3, at end of report). Although mean daily flow values have been computed in NWIS since the adoption of the database, different Water Science Centers and field offices have archived different amounts of ancillary data, such as ratings and shifts, throughout the 1980s, 1990s, and into the 2000s. Archiving of all shifts and ratings did not become universal and mandatory until the 2002 water year. Rating availability exceeded shift availability.

During the study period, 643 base ratings were available in the database (table 4, at end of report). In this report, "the database" refers to the Virginia node of the NWIS. Unless

another state is specified, references to NWIS also refer to the Virginia node.

Base ratings are each stored as a separate file, and all files include explanatory comments. Therefore, base ratings are straightforward to inventory. Shifts are stored in a more complicated fashion than ratings. All shifts for each site are stored together in a table. Each shift is stored as multiple entries with varying numbers of fields per shift and varying amounts of metadata, depending on when the shift was created and the nature of the shift. Because all shifts were associated with beginning dates and times, the simplest way to inventory them was to filter them by time.

Many of the shift entries, however, represent the same shift entered for multiple beginning times, and there is no straightforward way to identify and group them. The number of points needed to define a shift varies. The magnitude of an individual shift frequently varies during the course of the shift. More than one shift can be in effect simultaneously at different parts of the rating. Comments for some entries indicate that the shift is continued unchanged when the record is being updated. Some shift entries exist solely for transitions across the water year (from September 30 to October 1). Some hydrographers also follow a practice of creating, entering, and implementing shifts of zero value in order to compute flow values directly from the base rating, instead of ending the previous shift. Had the entire set of shifts included comments, repeated shifts probably could have been reliably identified. With incomplete explanatory information, however, retrospectively relating shifts with hydrologic events in bulk can be done only imprecisely.

October 1, at the beginning of the water year, was the most common date for implementing a rating; 161 ratings began on October 1 of one year or another (table 5). Another 157 ratings were put into effect on the date of a measurement. (Twice, a rating started on an October 1 when a measurement was made.) Most of these were probably convenient dates to convert a shift to a new rating, although 46 of the measurements were made on days with peaks, either floods or high-flow pulses, or flow events smaller than floods when flow rose but stayed within the channel. Sixty-two ratings were already in effect on October 1, 1990. Another two ratings were put in effect on a date with no approved daily flow value; these were dates before the associated streamgage was activated or reactivated. Of beginning dates with approved daily flow values, 199 came on peaks, either floods or high-flow pulses, and another 23 came on days when flow exceeded the 10-percent duration (D10). The remaining 217 ratings began on dates when no measurement was made, flow was less than the D10, and no peak was evident in the daily flow record.

About 23,000 shifts with unique beginning times were available for water years 1991–2013 (table 3). This set includes shifts that began before water year 1991 or before a streamgage was fully active, but the shifts were still in effect when the flow data used in this study were collected. Of the available shifts, 6,273 began on days when more than one

Table 5. Selected characteristics of daily flows on days that base ratings began at streamgages in Virginia, water years 1991–2013.

[<, less than; >, greater than; D10, flow exceeded or equaled on 10 percent of days; *italicized* entry is a subcategory of the preceding category; Categories are not mutually exclusive, individual ratings may belong to more than one category, and columns are not intended to add up to the total]

Category	Days shifts began	
	Number	Percentage
Total	643	100
Began on a peak, including high-flow pulses	199	31
In effect on October 1, 1990	62	10
Put in effect during the study period, but before daily value record began	2	0
Began October 1, total	225	35
- No peak on 9/30 or 10/1	*223*	*35*
Began on a day with flow >D10, on rise or recession but not peak	23	4
Began on any day when a measurement was made	157	24
- Flow >D10	*24*	*4*
- On a peak	*46*	*7*
- Not on a peak, and flow <D10	*105*	*16*
Other	217	34

shift began. The maximum number of shift entries, 32, came on a day when a measurement was made and a beaver dam subsequently was removed from a control over a period of several hours (October 4, 2005, at 01671100, Little River near Doswell, VA).

Setting aside the multiple shifts made on the same day at the same site, there were records for days with 16,853 unique shifts beginning at streamgages during water years 1991–2013 (table 6). Forty-one percent of shifts (6,842) began on days when the daily flow record showed a peak. These peaks included floods and high-flow pulses. For this analysis, a fairly liberal definition of a high-flow pulse was used: flow on a day that was greater than flow on either of the two preceding days or the subsequent day. Additionally, the days following rises in flow were identified and tallied separately, and generally represent days when a peak was receding; 7 percent of days when shifts began (1,144) were the days following peaks.

Because shifts were developed using unit flow values, not daily flow values, flagging flow events using daily values can result in some errors related to time resolution. For instance, comments associated with shifts indicated that many began on a rise that peaked during the evening or night when the daily value for the following date was greater than the daily value on the date of the peak. More than a thousand shifts

began on days of high flow although not on the peak. Seven percent of shifts began on such days when flow exceeded the D10 (1,135), and about 1 percent of those (168) began on days when flow exceeded the 1-percent duration flow (D1). These shifts were not necessarily intended to begin on the peak. Scour shifts often begin at the start of the rise and are in full effect at the peak, whereas fill shifts begin on the peak and are prorated through the recession.

Not all shift beginnings were clearly associated with an event. October 1, the first day of the water year, was ordinarily a convenient but arbitrary day to begin a shift. It was a common begin date for a set of shifts filtered to one per day; 5 percent (797) of the 16,853 shifts began on October 1 (table 6). Many shifts began the day that a measurement and streamgage inspection was made; 34 percent (5,681) of shifts began on these days. However, many of the measurements were made on days of peaks and high flows; 602 of the measurements were made on days when flow exceeded the D10, and 1,365 began either on the day of a peak or the day following a peak. There was overlap between days of peaks and days of high flows, but the upshot is that 24 percent of shifts began on days when a measurement was made, not on a peak or the day after a peak, and when flow was less than the D10. Shifts begun on days of medium or low flow and without peaks were not

Table 6.   Selected characteristics of daily flows on days that shifts began at streamgages in Virginia, water years 1991–2013.

[<, less than; >, greater than; D1, flow exceeded or equalled on 1 percent of days; D10, flow exceeded or equalled on 10 percent of days; *italicized* entry is a subcategory of the preceding category; Categories are not mutually exclusive, individual shifts may belong to more than one category, and columns are not intended to add up to the total]

Category	Days shifts began	
	Number	Percentage
Total	16,853	100
Began on a peak, including high-flow pulses	6,842	41
Began the day after a peak	1,144	7
Began October 1, total	797	5
- No peak on 9/30 or 10/1	*572*	*3*
Began on a day with flow >D1, on rise or recession but not peak	168	1
Began on a day with flow <D1 but >D10, on rise or recession but not peak	967	6
Began on any day when a measurement was made	5,681	34
- Flow >D10	*602*	*4*
- On a peak	*831*	*5*
- Day after a peak	*534*	*3*
- Not on a peak, and flow <D10	*4,024*	*24*
Other	3,136	19

necessarily arbitrarily associated with the measurement date. Controls are sometimes cleaned during streamgage inspections, which in turn results in one or more shift entries showing a return to the base rating. In the case of scour or fill shifts, it would be common (if not universal) practice to make a shift entry the day of the measurement for an existing shift, even when the shift was carried without change.

Frequently, shifts began at multiple streamgages on the same date, which also demonstrates the effort made to associate shifts with hydrologic events (table 7). The maximum number of streamgages with shifts beginning on the same date was 87, on October 1, 2010, a day when, in addition to being the beginning of the water year, 52 streamgages had a high-flow pulse, 38 had flow between the D10 and D1, and 9 had flow exceeding the D1. On 41 days, shifts began at 30 or more streamgages. Of those days, 11 were October 1 of one year or another, including several years when flow was high at several streamgages on October 1. The greatest number of streamgages with shifts beginning on a different date, 63, came on January 31, 2013.

Determining the precise number of days on which shifts are in effect was impractical because of the complexity of the shift dataset in combination with an incomplete set of explanatory comments. The shift dataset includes shifts of 0 feet that were created and put in place for the convenience

of hydrographers at a particular site, some of which include comments to the effect that the rating was used directly for the designated period. Additionally, more than one shift could be in effect at different points on the rating at the same time. Unraveling the shift process might have been done with more complete electronic documentation.

Timing of record working changed markedly during 1991–2013 (figs. 2 and 3). The relation of the start dates of shifts to dates of the final modification gives an approximate idea of when the record was worked and represents the best means available to estimate, in general, when the various shifted ratings used in this study were likely to have been developed and implemented.

During the early 1990s, record working was done primarily on an annual basis during a distinct office season, winter and spring (fig. 2). Few records were worked during the summer and fall when streamgage maintenance was done. From 1991 through 2001, the median number of days between the start date of the shift, the first date of data for which it was intended to modify, and the date it was created in the office by a hydrographer, fluctuated between about 240 and about 300 days. The 75th percentile of days between start date and creation date of shifts was more than 365 for every year during that period. Beginning in 2002, in recognition of the growing importance of near-real-time flow data to data

Table 7.   Dates on which shifts began at 30 or more streamgages, and flow characteristics for that day at the streamgage in question in Virginia, water years 1991–2013.

[<, less than; >, greater than; D10, 10-percent flow equalled or exceeded 10 percent of the time; D1, flow equalled or exceeded 1 percent of the time; DV, daily value or mean daily flow]

Date	Flow characteristic on the given date					Total number of streamgages for date
	<D10	D10<DV<D1	>D1	Peak or high-flow pulse	One day after peak	
10/1/2010	40	38	9	52	2	87
10/1/2007	83	0	0	2	6	83
1/31/2013	22	9	32	25	2	63
10/1/2006	58	1	0	11	32	59
10/1/2009	58	0	0	0	2	58
6/28/2006	4	23	30	45	2	57
10/27/2007	33	18	2	34	2	53
10/1/2002	53	0	0	0	1	53
10/1/2008	49	0	0	2	5	49
11/20/2003	1	17	30	33	0	48
9/19/2012	32	15	0	32	1	47
11/30/2005	9	19	19	29	0	47
12/8/2011	3	20	23	28	0	46
5/8/2013	9	16	20	25	1	45
12/1/2010	8	22	14	38	0	44
7/8/2005	15	14	15	35	0	44
2/23/2003	0	2	42	30	1	44
12/12/2008	17	21	3	25	0	41
5/7/2013	20	11	7	9	0	38
10/1/1997	38	0	0	6	16	38
1/15/2013	35	2	0	0	0	37
9/27/2009	28	7	1	24	0	36
10/30/2012	10	5	20	25	0	35
10/1/2001	35	0	0	2	2	35
4/23/2006	11	20	3	22	0	34
4/16/2007	1	20	13	27	0	34
1/16/2013	16	10	7	14	2	33
12/2/2010	5	24	4	24	0	33
10/9/2005	8	9	16	30	0	33
2/7/2004	2	20	11	18	0	33
12/27/2012	11	18	2	23	0	31
3/29/2005	0	16	15	19	2	31
9/29/2004	0	0	31	29	0	31
10/1/2004	9	20	2	3	13	31
4/14/2004	0	22	9	22	0	31
10/15/2001	30	1	0	17	0	31
10/1/1994	31	0	0	1	0	31
3/1/2012	7	18	5	20	0	30
10/1/2003	27	3	0	0	1	30
11/13/2002	3	26	1	25	1	30
10/1/1999	14	7	9	22	2	30
Subtotals	**835**	**494**	**395**	**828**	**96**	**1,724**
Totals for all dates at all sites	**11,085**	**3,691**	**2,002**	**6,842**	**1,144**	**16,853**

users, a greater effort was made to work records continuously. The median delay between the start date of a shift and its final modification decreased by about 4 months from 2001 to 2002 (fig. 3). Even so, many records required review and revision after more data had been collected, and one-quarter or more of shifts had delays of 3 months or more through 2013. During water years 1991–2013, one-half of the shifts had a delay between start date and final modification of about 60 days only in 2012 and 2013. Because 60 days is close to the 8-week interval between routine streamgage visits, these 2 years represent the first time when the expanded shifted rating saved in the database was more likely than not to be the one used to generate provisional data served to the internet. Even in those years, though, more than one-quarter of shifts were modified 90 days or more after the shift's beginning date. Because defining a shift that affects the stage-flow

relation through a range of flows requires multiple measurements made during multiple trips, there will be limits to how quickly shifts can be completed, even with the most diligent efforts possible to work records continuously.

Vertical and horizontal banding is evident in the plot of shift start dates relative to final modification dates (fig. 2). Horizontal bands represent days when large numbers of shifts were put into effect on the same day; these might be days when many shifts were approved but are artifacts of data computation. Vertical bands are more interesting. Because they represent days when many shifts began, vertical bands signify the days when hydrographers identified a hydrologic event likely to have altered the control and caused a shift at multiple streamgages. Vertical gaps represent periods when hydrographers judged that no events took place at any streamgages that changed controls and required a shift.
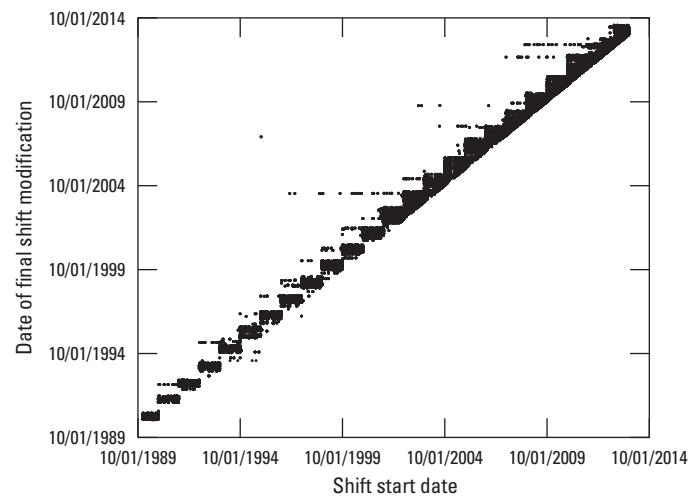
Figure 2.   Relation between start dates of shifts and dates of final modification of shifts at streamgages in Virginia, water years 1991–2013.
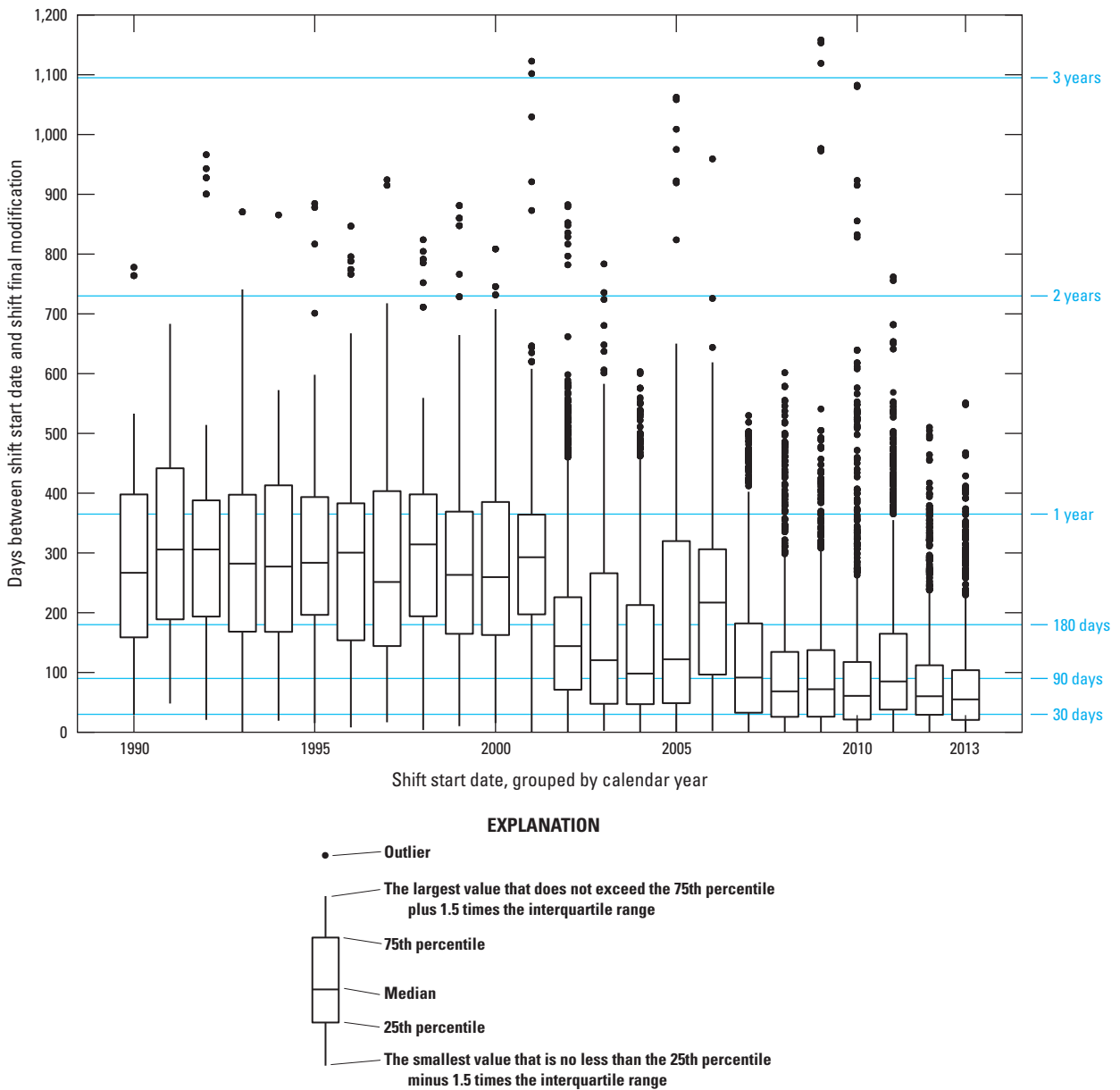
Figure 3.   Number of days between start and final modification of shifts at streamgages in Virginia, 1990–2013.

Patterns in the Stability of Stage-Flow Relations

Ratings change through time as hydraulic controls change. Minor changes are common and are the principal reason for repeated flow measurements made at a streamgage. Major changes are caused by disruptive events, such as major floods; human activities, such as channel reconfiguration or bridge construction that change streambeds and banks; or even deliberate events such as moving the streamgage or building or removing a weir. Some disruptive events are random. Some may be nonrandom but difficult to anticipate or avoid when streamgage locations are selected.

Patterns of streamgage ratings through time may be thought of as punctuated equilibria. Disruptive events and resulting major changes are relatively rare. Streamgage ratings commonly remain at equilibrium for years or decades between the disruptive events. The length of periods of equilibrium, and routine departures from them, are of primary interest in this discussion of rating stability and the manner in which it relates to the reliability of streamgages during routine periods.

This analysis was done in an iterative manner. The following sections discuss major parts of this analysis. Flow measurements were plotted and curves were fitted through them. Residuals from the curves (the difference between the observed and predicted value of the dependent variable) were plotted as a time series. Patterns in the time series were compared to patterns in the scatter plots, and major changes were noted. These major changes were used to define "rating families" or series of ratings and shifted ratings representing periods of equilibrium. Curves were then fitted through the rating families, and time series of the residuals were used to check their identification and refine their designations.

Ratings and shifts are depictions of the stage-flow relation and are developed from flow measurements. Much of the analysis in this section was done using flow measurements. Flow measurements are the only available method to quantify the shiftiness of controls, although certain types of shifts can be developed in the absence of flow measurements. Leaf shifts, for instance, are needed for streams flowing through deciduous forests when autumn leaves fall from the trees into the stream and accumulate into a leaf mat on a streamgage control. These leaf mats typically remain in place until a high- or moderately high-flow episode washes them off the control. They can be detected on real-time hydrographs in the absence of flow measurements, as a gradual, multiday rise in stage in the absence of precipitation, in Virginia, during October or November. Leaf mats form during a season when flows are at or near annual lows.

In an iterative process, a LOESS curve was fit through all available flow measurements for all the streamgages in Virginia's real-time network as of September 30, 2013, with at least 20 flow measurements with positive flow values. This curve served as an average long-term rating. For each measurement with a positive flow value, residuals from the curve

were calculated. Measurements with negative or zero flow values were not considered as part of this analysis because these values do not exhibit consistent stage-flow relations.

A set of plots was developed showing three plots for each streamgage: (1) gage height and flow for all the measurements and the LOESS curve, (2) the residuals plotted by date, and (3) the residuals plotted by Julian date (appendix 1). Curves were fit and plotted using R, ggplot2, and plyr (R Core Team, 2014; Wickham, 2009; Wickham, 2011). Residuals by date were used to explore long-term trends, and residuals by Julian date were used to explore seasonal trends. Printouts of the plots grouped by major river basin or by field office assignment were taken to the three streamgaging field offices active in Virginia: the USGS field offices in Richmond and Marion and the VDEQ field office in Charlottesville. Hydrographers were interviewed about the streamgages with which they were familiar, and notes and sketches were made on the printouts to describe the rating characteristics, measurement quality, streamgage history, and other factors that the hydrographers considered important about the streamgages. The interview information was compiled and merged with descriptive information available from USGS databases (table 8, available online). These plots and statistics were also used to identify and explain major outliers.

Development of Long-Term Average Ratings

To evaluate long-term stage-flow relations, curves were fitted through points representing all available flow measurements. Different curves were compared. Periods when the relation changed little were determined, and curves were then fitted through points representing flow measurements from these periods.

Comparison of Smoothing Curves

The LOESS curves that initially were fitted through the measurements fitted poorly and resulted in time-series plots that in some cases were dominated by obvious artifacts of fitting. Different smoothers were then compared to achieve a better fit (fig. 4): (1) linear regression in logarithmic space, (2) Gaussian LOESS with span=0.5, (3) symmetric LOESS with span=0.5, (4) symmetric LOESS with span=0.75, (5) symmetric LOESS with span=0.25, and (6) generalized additive model (GAM).This comparison was done for all rating families in the study, although a single representative site, 01634000, North Fork Shenandoah River at Strasburg, was chosen to illustrate the differences in smoothers (fig. 3). In general, small changes in span made small differences to the pattern and fit of the curves, and the settings used in these plots were broadly representative of ranges of span. The differences between the two families of LOESS curves were not great. The "symmetric" family tended to fit these data slightly better than the "Gaussian" family, but in general, both families had many of the same weaknesses.
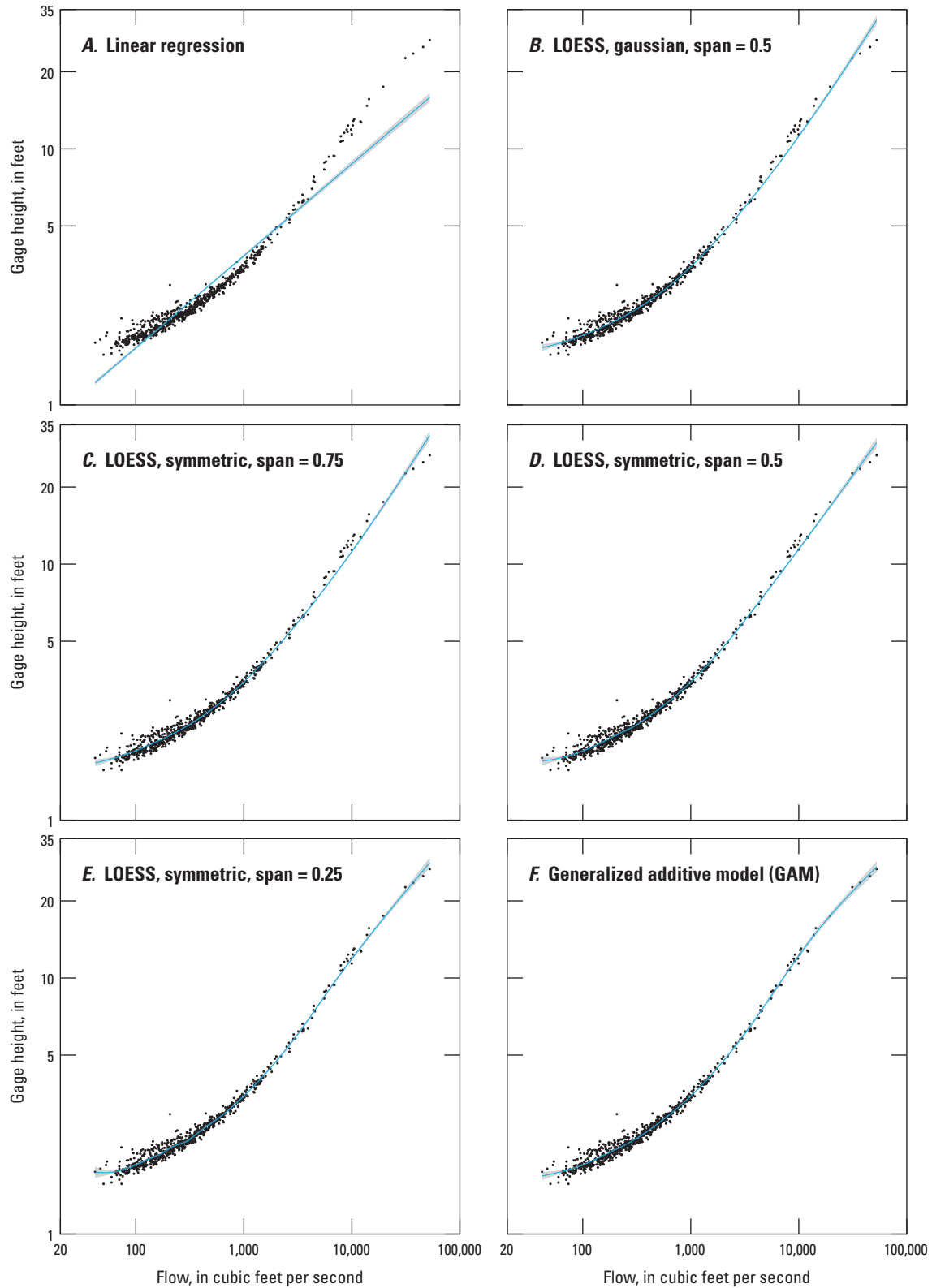
Figure 4. Rating curves for stage-flow relations for streamgage 01634000, North Fork Shenandoah River at Strasburg, VA, with six smoothers applied: *A*, linear regression, *B*, Gaussian LOESS, *C*, LOESS, symmetric 0.75, *D*, LOESS symmetric 0.5, *E*, LOESS, symmetric 0.25, and *F*, generalized additive model. Shading represents 99-percent confidence interval.

The span of a LOESS curve is a measure of how localized the curve is. A small value of span represents a highly localized curve, which uses relatively few of the points in the plot and only those closest to that section of the data. Values of span less than 1 correspond to the proportion of points that is used for computing the regression. At a span of 1, all the points in the plot are used, although they are weighted. With an infinite span, all points are used without weights so that it is functionally a linear regression. A GAM is a generalized linear model in which the linear predictor is given by a user-specified sum of smooth functions of the covariates plus a conventional parametric component of the linear predictor; models are fitted by penalized likelihood maximization, in which the model likelihood is modified by the addition of a penalty for each smooth function (Wood, 2011, 2014).

The fit of the LOESS curves to these data varies, but many are poor. Fit through the high measurements was systematically poor with, as an example, the various LOESS fits for streamgage 01634000, North Fork Shenandoah River at Strasburg, VA, showing typical problems (fig. 4). Actual ratings are carefully drawn (or fitted) through the highest measurements, those made when stage is controlled by a channel feature instead of a bed feature. Frequently, LOESS curves missed these points, and these points had large residuals. Although rating families could be separated using the residuals from these curves, these residuals were problematic for further statistical analysis. In contrast, the GAM curve fitted the high measurements neatly.

In some cases, decreasing the span of the LOESS curve improved the fit of the high end, but this often came at the expense of causing the fit through the bulk of points to be eccentric or erratic. Residuals from these curves plotted against date were challenging to interpret because of the prevalence of artifacts.

This pattern is general, not universal. A substantial number of the GAM curves have a worse fit through the data than one or several of the LOESS curves, even at the high end of the plot. A tally was made of which of the five types of smoothers used in the rating family plots had the best fit. Criteria for best fit include, in order of priority, splitting the difference cleanly when plots appeared to show multiple populations; handling changes in data density, particularly handling changes in the pattern of high measurements likely to represent the break onto the flood plain; insensitivity to small groups of outliers near a dense cloud of points; and smoothness of the curve.

The GAM curves have the best fit for 214 of the 331 sets of plots; this comparison included 30 rating families from partial-record and crest-stage sites that were ultimately not included in this report. In cases where the fit was not appreciably better for one type of curve than for another, the curve was counted with the family that less frequently had the best fit. For many of the sets of plots, several of the smoothers fitted well; for many of them, none fitted particularly well. The GAM curves seemed to excel at dealing with changes in data density. Often, the LOESS curves appeared to be affected by a dense cloud of data from a different range of values. Although no attempt was made to quantify which of the smoothers had the worst fit, the GAM plots generally had poor fits only if all the curves had poor fits. In contrast, LOESS curves with low span values (0.25 and 0.5) in some cases showed the best fit (40 and 20 times, respectively) but often fitted the data erratically and would have produced residuals that would have been difficult to interpret.

Classification of Rating Families

Rating families were classified graphically in an iterative process. Plots were developed that included points of all the flow measurements that were stored in NWIS for each streamgage active in the real-time network as of November 2013. Measurements with negative or zero flow values were removed from the dataset. Negative flows were clear indicators that streamgages did not have a simple relation between stage and flow. Observations of zero flow, similarly, could not be conclusively associated with their corresponding gage height in a meaningful way because, when the gage height of zero flow for a particular cross section is reached, stage could continue to drop. Once these measurements were removed from the local database, all streamgages with 20 or more measurements were retained for analysis.

Curves were fitted through plots of gage height and flow. An initial series of plots was developed with a curve fit through all the points for each site, and a time series of residuals from these curves was plotted alongside the first plot (fig. 5; appendix 1). This process produced many artifacts and erratic patterns in the time series, but major changes could be identified. The gage height–flow plots were examined for clustering, but to lead to a classification as a rating family, a cluster had to correspond to a change in time that was evident in the time series plot. Types of changes in the time series plots used to classify rating families were, in order of priority, (1) abrupt steps upward or downward, (2) sloped transitions between flat steps, (3) major increases or decreases in variability, and (4) breaks in record greater than 2 years coinciding with differences, even ambiguous differences, in the appearance of plots.

The major changes identified in the initial set of plots were discussed in the hydrographer interviews. Notes from these interviews, in combination with station records from the Site Information Management System (SIMS), field observations recorded on measurement forms, and in some cases, office records contemporaneous with the rating changes were used to explain the rating changes.

Once major changes had been identified and confirmed, measurements were designated as belonging to rating families. Both gage height and flow were $\log_{10}$ transformed. A new series of curves was fitted through the data, by major rating
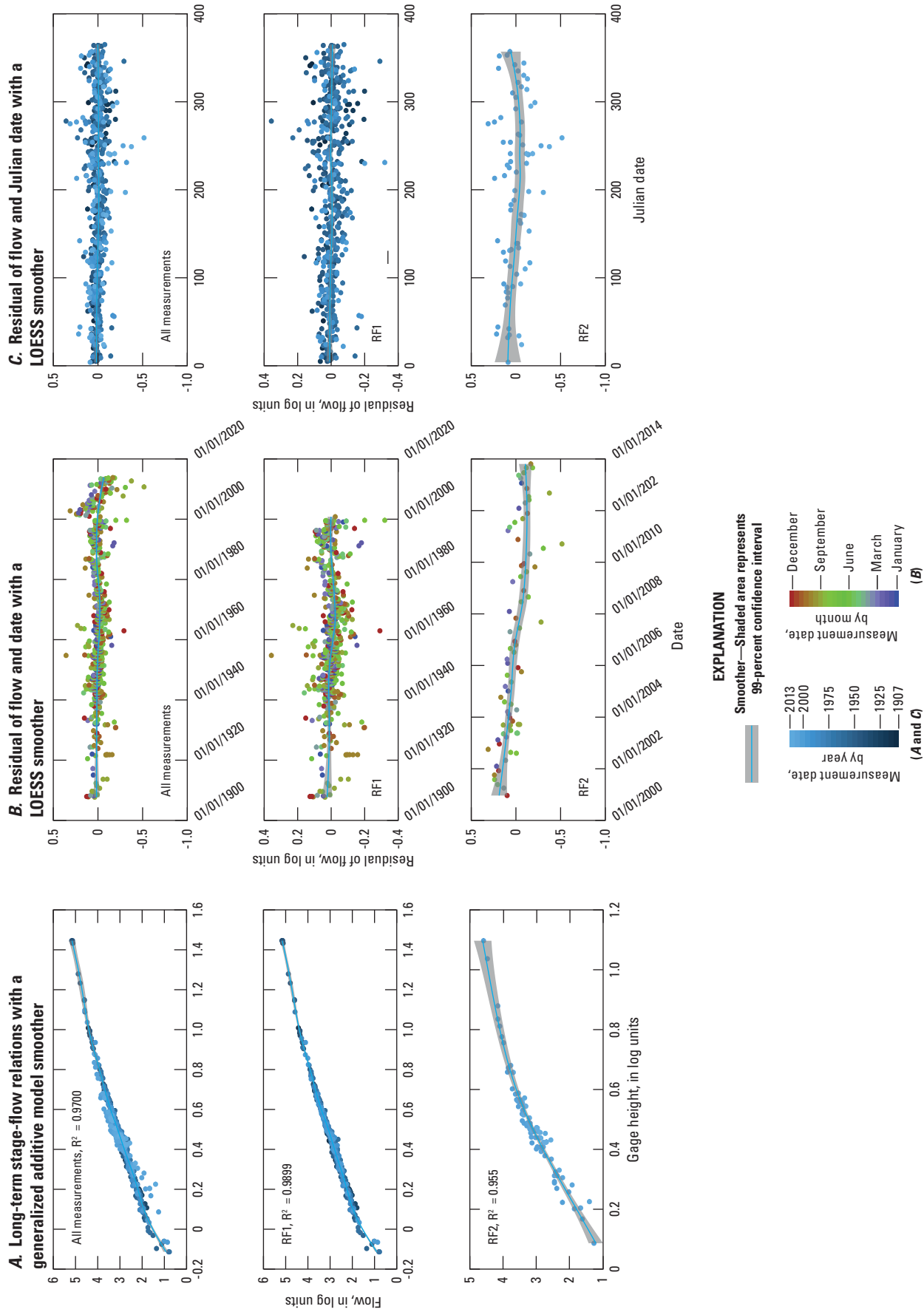
Figure 5.   Streamgage 01668000, Rappahannock River near Fredericksburg, VA, showing: *A*, long-term stage-flow relations with a generalized additive model smoother, *B*, residual of flow and date with a LOESS smoother, and *C*, residual of flow and Julian date with a LOESS smoother. (R², coefficient of determination)

family, and residuals again were captured and plotted as a time series. Rating family classifications were checked graphically, and further subdivisions became evident at this time. Rating family designations in the database were updated, and a set of plots was developed that displayed, by site, a complete time series of residuals from the rating family curves. Transitions between rating families were checked and where necessary corrected, but no new rating families were designated in this iteration. These plots are included in Appendix 1.

Rating families were identified from the measurement plots. If clusters in the gage height flow plots could be related to major step trends or changes in variability in the residual time series, these sets of measurements were considered candidates for a rating family. Attempts were made to relate the events that changed the control to the observed differences in the plots. At the 174 sites, 301 rating families were identified (table 9, at end of report). At 107 sites, all measurements fit a single rating family.

As an example of the classification process, the plots for 01668000, Rappahannock River near Fredericksburg, VA, showed two rating families (fig. 5). Measurements from the establishment of the streamgage until 2000 generally clustered together on the plot of flow relative to gage height. The time-series plots of residuals show occasional scatter and outliers but no obvious trend, whether stepped or gradual. In 2000, however, the relation between gage height and flow changed. Points on the gage height–flow plot that represent later measurements have a different slope than the previous points. This is seen in the residual of flow time series as greatly increased scatter beginning in 2000. Site records indicate that the streamgage was moved in October 2000. Measurements made before October 2000 are designated as belonging to Rating Family (RF) 1 and subsequent measurements as belonging to RF2. Curves are then fit separately to each rating family; residuals were captured from the curves and plotted as time series and by Julian date for each rating family. The new curve for RF2 fits those points better than the original curve fit all points. The coefficient of determination (R^2) for RF1 is higher than that for the entire set of measurements (0.989 as compared to 0.9700); R^2 for RF2 is lower (0.9550). The time series indicates that since 2000, residuals have been negative or that less flow is associated with a given gage height. This may be the result of a long-term increase in deposition on the control or possibly some seasonal increase in macrophyte growth. If macrophyte growth were the likely cause, it might show up as large, negative residuals during summer and fall. This is in fact reflected in the time-series plot, although most of the recent winter measurements are lower than any measurements made before 2003. The plots of residuals and Julian date show little seasonal change for RF1, although variability was generally greater for the second half of the year. For RF2, overall variability is greater than for RF1, but the LOESS curve dips during summer when macrophyte growth is generally at its maximum.

At 67 sites, two or more rating families were identified. The maximum number of rating families was 7 at Chestnut

Creek at Galax, for a total of 127 rating families that were delineated as separate. Of these 127 rating families, documented explanations were found for 67. The most common reasons for the control to change enough to represent a new rating family were moving the streamgage (28 times); floods (26 times); and construction activities, including bridge construction and removal, weir and control construction and removal, and channel or bed modifications (13 times). Sixteen of the rating families were classified at the end of a period of no data, including hiatuses in operation and periods when the streamgage was operated but measurements were not entered to the database. Forty-two rating families were identified from graphical appearance of the plots; eight of these had inconclusive or ambiguous documentation of stream channel changes.

Rating family changes related to floods represent a type of major change which real-time flow-data users might be able to anticipate. Of the 25 new rating families that were created by floods, most (18) were caused by major floods that changed ratings at more than one streamgage. The November 1985 flood caused by Hurricane Juan caused 9 of these changes, the June 1972 flood caused by Hurricane Agnes caused 3, and 2 each were caused by the August 1969 flood (Hurricane Camille), the January 1996 flood, and the September 1996 flood (Hurricane Fran). A major flood may cause a substantial rating change in any stream. Floods caused major rating changes in mountain streams with highly stable bedrock, or bedrock and boulder channels, although other nearby streams that also experienced major floods from the same storm showed small or no changes. Provisional flow data from any streamgage that has recently experienced a major flood, regardless of historical stability, is more uncertain than usual until post-flood evidence emerges that the rating remained stable or has again been well defined.

In many cases, clusters of several consecutive measurements temporarily departed from the time series; these were included for analysis but checked for explanations. Often, the departure was caused by human activities, such as a construction of a temporary dam used to facilitate bridge construction. Sometimes the departure was caused by beaver activity. Construction that subsequently affects the stage-flow relation at a streamgage typically will be reported to USGS in advance, and the information is likely to be made available to water-data users. Beaver activity is difficult to anticipate but highly persistent. The presence of active beaver populations can be regarded as a characteristic of a site, as well as a strong predictor of degraded quality of flow records.

Flow measurements made when the stream is at or near flood stage are typically included in rating analysis for years or decades, and ratings are carefully fitted through them. Although changes are sometimes observed in the high end of ratings and repeated flood measurements must be made whenever possible, the practice of including historical high-flow measurements in ratings has been supported by repeated observations at many sites. Because these measurements are used to develop currently active ratings, the measurements are commonly included in NWIS, even if low-flow measurements

that were made during the same years have never been entered into the database. The high-flow measurements often show up as outliers on the time-series plots, however, because GAM curves developed for this study and fit to the full set of measurements sometimes miss these points and because these measurements are isolated in time. The high-flow measurements were included, even when they appeared to be outliers through an artifact of curve fitting, and represent one of the sources of error in the R^2 of the GAM models.

Measurements made since the full implementation of NWIS in 1988 are intended to include information on whether or not the measurement was known to be in error and therefore excluded from the rating study during the year it was made. Common reasons for not being used include equipment failure or interference caused by flowing debris. Measurements made prior to the development of NWIS that were subsequently entered did not necessarily include this information. Measurements were screened as outliers both visually, from the plots, and by a check of divergence of four standard deviations from a running average of residuals in the time series. Greater effort was made to confirm visual outliers that indicated unusually high flow for a given gage height than was made for the opposite. Outliers indicating unusually high flow, when they result from accurate measurements, indicate temporary scour in the control. Temporary scour is less common than temporary backwater. When field or office notes indicated that outliers were considered to be unreliable measurements when they were made, they were excluded from analysis.

One of the limitations of the rating family classification is that, because classification was done graphically, it was subjective. Two alternate approaches were explored in an attempt to address this limitation. First, broken-stick regression and change-point analysis were explored but rejected as potential objective methods for classifying rating families. When applied to data from sites with clearly identified rating family changes that corresponded to well-documented causes, neither correctly identified the rating families. Second, the existing rating families were examined on an expanded scale. Rating families were further subdivided, and explanations were sought for the 108 new candidate rating families that were identified. Few of the new candidate rating families could be matched with explanatory events; only 1 of 108 candidates could be matched with remarks in the database or with measurement front sheets. Although base ratings were available for some of these candidate rating families, the base ratings generally changed at different times than this group of rating families. Because of the lack of corroborating evidence, this entire set of rating families was considered generally invalid and was abandoned.

During iterations of the curve fitting, GAM curves that modeled gage height as a smoothing function of flow (GAM_{GH}) and that modeled flow as a smoothing function of gage height (GAM_Q) were developed and compared. The former curves follow the same convention as USGS streamgage ratings. Gage height is on the y-axis of a plot, and like actual stream rises and recessions, shows up as a vertical change. The latter curves, flow modeled as a function of gage height, seem superficially to mimic flow computation that might be done in a situation where gage height was known and flow is computed from an equation; however, for actual streamgages, flow is more commonly determined from gage height using database operations and matching a lookup table than computed from an equation. Both of these formats had advantages. When gage height is used on the y-axis as the dependent variable, stream filling and downcutting are portrayed in the same direction as they move in the physical world. When flow is used as the dependent variable, it facilitates comparison among sites for some purposes, although the relative importance of an arbitrary unit of flow is greater in a small creek than a large river.

The two sets of GAM models were compared graphically. For most sites, both models fit the available data equally well (215 of 301 rating families). The GAM_{GH} models showed a better visual fit about twice as often as the GAM_Q models (56 and 23 rating families, respectively). For the other seven rating families, neither model was judged to fit well.

Error terms for the two sets of GAM models, as well as Spearman's rho correlation coefficients for gage height and flow within each rating family, were compared to the stability classes on the basis of expert judgement. Setting the classes Excellent, Good, Fair, and Poor equal to, 4, 3, 2, and 1, respectively, and performing correlation analysis resulted in Spearman's rho correlation coefficients among rating families of 0.3790 for R^2 for GAM_Q, -0.4687 for Spearman's rho within each rating family, and 0.2982 for R^2 for GAM_{GH}. Boxplots of these two error terms showed slightly more separation among classes for the R^2 of GAM_Q than the other two terms (fig. 6). The better correlation among sites between stability classes for the R^2 of GAM_Q than for R^2 of GAM_{GH} was contrary to the visual inspection of plots. Plots for those sites with a relatively high R^2 for GAM_Q and a relatively low R^2 for GAM_{GH} indicate that those sites predominantly had insensitive controls or controls where, at the low end of the rating, the change in flow was large relative to the change in stage.

Owing to the iterative nature of the analysis in this study, several stability metrics that have not yet been discussed in this report were important to the final line of evidence used to select GAM_Q over GAM_{GH} as the preferred model for fitting measurements. The section "Relations Among Stability Metrics" farther on describes the manner in which the proposed metrics that were determined to be meaningful showed stronger correlations among sites with R^2 for GAM_Q than among sites with R^2 for GAM_{GH}.
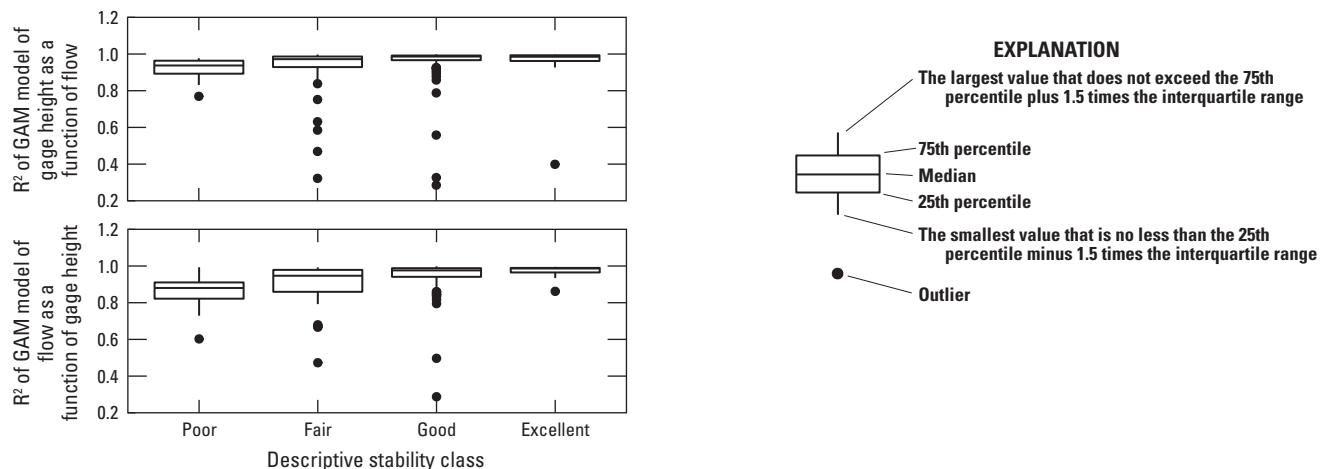
Figure 6.   Distribution of variability metrics for stage-flow relations, by descriptive stability class, for streamgages in Virginia active on September 30, 2013. (GAM, generalized additive model; R^2, coefficient of determination)

Seasonal Changes to Stage-Flow Relations

Residuals from the fitted stage-flow curves, plotted by Julian date, show differences in rating stability throughout the year (appendix 1). Ratings can be grouped into three general classes. The first class, which is represented by 03173000, Walker Creek at Bane, VA, generally has been stable through time and at all times of the year (plate 1). At these sites, established ratings change rarely, if ever, and temporary shifts are also rare. At Walker Creek, the R^2 of the GAM_Q model is 0.9966, and all available measurements fit a single rating family. A handful of low outliers, representing backwater conditions, have been observed. Most of these outliers were in the winter, and they were likely caused by ice.

The second class, which is represented by 01631000, South Fork Shenandoah River at Front Royal, VA, is generally stable through time and consistent during winter and spring but usually shifts in the summer or fall. At these sites, the bed is typically stable, but seasonal plant growth or leaf accumulation on the control is routine. Although routine, the magnitude, duration, and timing of these shifts are different every year, and preliminary flow data at these sites might or might not need to be corrected. At South Fork Shenandoah River at Front Royal, all measurements fit a single rating family, the trend line for the long-term time series is generally flat, and R^2 of GAM_Q is 0.9694. There have been two periods when macrophyte or leaf shifts were unusually large, in the 1950s and since about 1988. Most of the low outliers were between Julian dates 200 and 300, or July through October. The control description (table 8) discusses shifting caused by aquatic growth and leaf fall; subsequent accumulation of leaves in streams rarely begins before September, so the largest shifts likely were caused by macrophyte growth.

The third class, which is represented by 01658500, South Fork Quantico Creek near Independent Hill, VA, especially RF1, is somewhat unstable at all times of the year. Rating instability at these sites is likely to be the result of a shifting, unstable bed. As at South Fork Quantico Creek, these sites are commonly subject to seasonal shifting as well. Although shifts are frequent at this site, they are not huge and scour is usually followed by fill. An exception was a flood in 1990 that caused a new rating family, but neither rating family had extreme variance; R^2 was 0.9160 for RF1 and 0.9372 for RF2.

A banding pattern similar to that in the plot of residuals by Julian date for 02030500, Slate River near Arvonia, VA, is seen for some of the sites (plate 1). This pattern was investigated to determine whether it was an artifact of Julian date computation or was some other type of artifact. It was real. It shows up at sites operated by field offices that maintained the same field trip schedule consistently throughout the period of record. At these sites, measurements were consistently made the same weeks of each year.

Long-Term Changes to Stage-Flow Relations

Patterns in rating residuals plotted as a time series show that ratings tend to reach equilibria of varying stability punctuated by disruptive events. Disruptive events, as demonstrated by the explanations for rating families (table 9), include major floods and human construction activities. The equilibria, generally, reflect conditions when a stable or relatively stable feature has formed or been built and that feature serves as the control. The time to equilibrium varies depending on the nature of the stream channel and the disruptive event. Disruptive events, such as weir construction, led to almost immediate

equilibria, but some floods caused changes that took extended periods to reach new equilibria.

Two examples of sites at which controls were changed by floods, but different amounts of time were needed to become stable, are 02021500, Maury River at Rockbridge Baths, VA, and 03207800, Levisa Fork at Big Rock, VA (plate 2). At the Maury River streamgage, where the channel is composed of bedrock and large boulders, the January 1996 flood altered the control so that flow at a given gage height increased. Because it increased throughout the range of stage, as shown by nearly all points that fall above the GAM curve on the stage-flow plot representing recent measurements, the control alteration might have been a large boulder moved downstream by the flood. Despite this change, all the measurements at this site were designated as belonging to a single rating family, with an R^2 of 0.9935. At the Levisa Fork streamgage, where the control is cobble and boulder, the April 1978 flood desta-bilized the control. Prior to this flood, the control exhibited regular but relatively minor seasonal shifting. After the flood, variability increased, and the channel began to downcut. Fol-lowing a major but undocumented change in 1988, variability decreased, but downcutting continued until about 2005. In 1978, a flow measurement of 57.9 cubic feet per second (ft^3/s) was made at a gage height of 4.12 ft; in 2013, a flow measure-ment of 61.1 ft^3/s was made at a gage height of 2.58 ft. The downcutting is further corroborated by hydrographer obser-vations that water levels in the pool decreased enough that the stilling-well intakes were above the water and required modification. All of the downcutting cannot be attributed to channel response to the 1978 flood, as opposed to land use and other possible activities, but that flood clearly was a disrup-tive event that marked the beginning of a period of change for the control.

Two other types of long-term changes to controls are illustrated in plate 2. Scour-fill changes are shown for 02065500, Cub Creek at Phenix, VA. At this streamgage, the control is sand and gravel, and it was affected by large woody debris. The earliest available data show that the stream was scouring the control until the late 1980s. It then filled over the next 10 to 12 years, while variability increased. In the early 2000s, the stream began to scour again and has continued through 2013.

At 02040000, Appomattox River at Mattoax, VA, the low-water control is thought to be a channel constriction, but shifting is caused by accumulation of sand and gravel in the streambed. Measurements have not been continuously avail-able since the establishment of this streamgage. The earli-est available data show little variation. The second block of available data, from the 1920s through the late 1950s, shows decreasing flow at a given gage height, which indicates chan-nel aggradation, filling, or possibly, if the low-water control is in fact a channel constriction, increased constriction. Data are available beginning in 1988. During the period when data were unavailable, the channel downcut or widened. Since 1988, however, the channel has been filling or constricting

again, a pattern that increased about 2002. This site also exhib-its seasonal shifting and, occasionally, a low measurement in the winter that might be affected by ice.

Estimated Provisional Flows (AltFlows)

Despite their limitations, provisional real-time flow data are indispensable for water managers. For some purposes, especially those related to flood warning and response, or for those for which precision is less important than relative change or timing, provisional data are likely to meet users' needs. Provisional low flows, however, are likely to be revised before they become final for three reasons. (1) Low flows are sensitive to small changes in the control. (2) Low flows are common during summer and fall, and coincide with algae and macrophyte growth and leaf accumulation. (3) Low flows can be technically challenging to measure accurately, especially in rough stream channels, leading to more erratic ratings in such streams. Low stage is also technically challenging to mea-sure in response to sediment deposition and where controls are insensitive. For users of provisional flows, especially low flows, quantifying differences between provisional and final flows would provide valuable insight into the reliability of provisional flows.

A long-term comparison of provisional data against final data would provide a simple, direct measure of the changes that the data undergo through USGS processing and indicate the reliability of the provisional data for user decision mak-ing. Indeed, if provisional data were archived for the period of interest, a comparison between provisional and final data would be straightforward. However, provisional data are not archived. The USGS flow time-series database Automated Data Processing System (ADAPS) was developed in a time when data storage was much more expensive than it is now. Storing all preliminary and intermediate data was impractical until the late 1990s or early 2000s, and reworking the database to do so was not a high priority for data managers and soft-ware developers. For most sites, the storage of final, corrected unit values for gage height and flow began in the late 1990s or early 2000s. Paper tapes and data collection platform files were archived, but reconstructing a complete provisional time series from them would require several staff years of effort and was beyond the scope of this study. New software with a planned release date in 2017 is designed to include preserva-tion of provisional data, as well as associated comments and computations that document and attribute each change in the data through time.

As a substitute for provisional flow data, an alterna-tive series of daily flows (AltFlows; fig. 7) was developed (Messinger and Burgholzer, 2017). The primary steps were to acquire and compile ratings and daily flows for periods when ratings were available. Periods with complete records of shifts and ratings were identified. Daily flows were acquired for

START

Determine station number ← Table of stations active as of September 30, 2013

Determine date and time ← Dates and times of flow measurements

Find rating number (RATNO) in effect ← Available from retrieval of base ratings

Find data descriptor (DD) in effect ← Available from retrieval of base ratings

Compile one-line commands

Retrieve individual expanded shifted ratings

Compile ratings into tables

Verify retrievals

Perform lookups

Compute AltFlows

Examine outliers and unexpected patterns in computed values

Do ratings need to be corrected?   Y

N

END

Figure 7.   Major actions and data sources for computing alternative flow (AltFlow) tables for Virginia streams, water years 1991–2013.

these periods. Expanded shifted ratings were acquired for days during these periods when flow measurements were made. Gage heights corresponding to mean daily flows were back calculated and identified as belonging to measurement-to-measurement periods. These gage heights were then evaluated against two sets of ratings, those in effect when the measurement-to-measurement period began (Q_{same}) and those in effect when the previous measurement-to-measurement period began (Q_{prev}). Q_{same} was used instead of the published daily values to avoid rounding errors. Daily mean flows were computed by averaging the unit values for each day but often failed to correspond to the flow increments in rating tables (fig. 7).

Several important sources of error in provisional flow data that are corrected in final flow data are missed by this process. Most important and common are errors that are not caused by changes to the control, and therefore are not corrected by changing ratings or shifts. These errors include ice-affected flows or missing records, which generally are estimated by hydrographic comparison to other streamgages. Errors in the stage record itself are relatively common for some sites, especially those with substantial sediment loads. These errors might be corrected or at least adjusted, or daily flows might be estimated for the period that was in error.

Another difference between provisional and approved data not accounted for by this procedure is that expanded shifted ratings were selected as snapshots at the times when flow was measured, and the tens of thousands of other rating changes were ignored. Days when measurements were made have no particular relevance to the beginning or ending of shifts and rating changes. About one-third (7,346 of 23,126) of shift entries began on days when flow was measured, and of these, 2,679 were apparently procedural entries for shifts that were implemented in multiple steps throughout the day. Forty-one percent of unique shifts (6,842 of 16,853) began on days of peaks, either floods or high-flow pulses, and another 7 percent (1,144 of 16,853) began the day after a peak; many of the shifts that began on days when measurements were made came on days of peaks and high-flow pulses. Prorating certain types of shifts through time is routine; the AltFlow procedure does not account for these changed shifts. As a result, the AltFlow time series is unlikely to have much relation to provisional data as they initially appeared on the web. It does, however, provide information on changes in the shifted rating from site visit to site visit and information on how the shifted rating changed throughout the range of observed flows.

AltFlow Development

AltFlow development involved inventory and assessment of ratings and shifts, acquisition of ratings and daily flow values, computation of Q_{same} and Q_{prev}, and validation of these computations through a series of checks.

Rating Availability, Acquisition, and Compilation

Availability of ratings and shifts varied by streamgage (tables 3 and 4). Although daily flow values have been computed in NWIS since the adoption of the database, different centers and field offices archived different amounts of ancillary data, such as ratings and shifts, throughout the 1980s, 1990s, and into the 2000s. Electronic archiving of all shifts and ratings did not become universal and mandatory until the 2002 water year. Rating availability exceeded shift availability. All ratings and shifts were stored with their effective dates. Although a base rating may have been archived at a relatively late date, if it had been in effect previously, it was stored in association with its earliest available date. In some cases, the effective date preceded the development of NWIS. In these cases, however, there was no reason to go back and enter previous shifts, so they were never entered. However, there was no reasonable way to retrospectively tell the difference between cases when a base rating was entered after it had initially been developed and cases when a base rating without need for shifting was entered and used to compute flow values. Therefore, the beginning dates for potentially valid AltFlows data were set at the first date for each streamgage for which both a base rating and a shift were available. This procedure incorporates the assumption that all ratings and shifts that had been used were continuously available once they were initially available, which was impossible to check without site-by-site, year-by-year comparison of available data to printed station analyses. However, on review of a summary of the number of base ratings and shifts available by year (tables 3 and 4), the assumption seemed plausible.

As discussed previously, preferred approaches to dealing with rating changes may vary by analyst and field office. It was, however, straightforward to avoid arbitrary differences between ratings and shifts by using expanded shifted rating tables, the final rating tables used in the database to compute flow. As discussed previously, ratings and shifts change frequently, sometimes abruptly and sometimes gradually; they may be implemented at once, prorated over a few hours during a rise or recession, or prorated over several weeks when weeds are thought to have been growing or leaves are thought to have been accumulating. To make the task at hand less impractical, expanded shifted ratings were retrieved only for the times when flow measurements were made.

Retrievals of shifted ratings were made for the precise date and time of the measurement. On days when stage changes, the measurement checks only the segment of the rating near that same range of stage; stated another way, an instantaneous flow measurement provides a reliable check for a published daily value for a day when flow did not change. Accounting for measurement timing on the retrieval was particularly important because extra effort was made to catch

high measurements, nearly all of which were made on days when flow changed.

Archived expanded shifted ratings were not readily available to the public, and retrievals required direct access to the command line of the Virginia Water Science Center NWIS server. The ratings that originally were not readily available to the public have been published (Messinger and Burgholzer, 2017). The tools and actions used to compute AltFlows are described in appendixes 2 and 3.

Special Conditions Affecting Some AltFlows

During the process of validating the AltFlow data, several extreme values were identified and investigated to determine whether they reflected (1) artifacts of the AltFlow development process, (2) special conditions related to the flow data collection and processing, or (3) exceptionally unstable controls. The extreme values that were identified as artifacts of the AltFlow development process were corrected. All the artifacts that were identified resulted from errors in the expanded shifted rating retrieval that in turn resulted from complications in the manner in which ratings were coded and stored. Special conditions related to flow data collection and processing that affected some AltFlows are discussed below. Other special conditions that resulted in modest rather than dramatic effects to AltFlows may have gone unnoticed.

Streamgage Datum Changes

On occasion, generally in response to scour at the streamgage control, the datum of the streamgage is changed. Often the change is made in order to avoid a zero or negative gage height, which would be undefined on log-scale plots; datum changes are always or nearly always positive because there is no practical reason to make a negative datum change. Datum changes are typically made in increments of one or more feet. Large datum changes (3 feet or more) would typically be made if continued scour was anticipated. Because the datum is arbitrary in the first place, these datum changes are made for the convenience of the hydrographers. The datum change itself is inconvenient, so datums are changed rarely.

Datum changes were made six times at streamgages for which valid AltFlows could have been computed (table 10). The sets of ratings for these six sites were adjusted for datum corrections. They are the only sites in the study to which a datum correction was applied during a period when valid AltFlows could have been computed. For each of the sites in table 10, the appropriate number of rows (200 for the three sites with 2.00-foot datum corrections, 300 for the sites with the 3.00-foot datum correction, and 3,099 for the sites with the 30.99-foot datum correction) was inserted into the columns representing expanded shifted ratings for all dates prior to the datum correction. All stage measurements in the rating tables now represent the same datum for each site. No manual change had to be made for the flow table; once the ratings were adjusted, the lookup functions were able to find the corrected gage heights without any further modification.

Moving a Streamgage

Sometimes it is necessary to move a streamgage. Reasons include, but are not limited to, stream channel migration away from the streamgage location, frequent deposition of sediment on the intake or orifice, demolition of a bridge or other structure to which the streamgage is attached, construction of a bridge or other structure that interferes with streamgage operation, structural damage to a gaging structure, and determination that a control is unstable and better record could be obtained elsewhere on the same stream.

Streamgages are sometimes moved from one location to another within the same gaging pool. Under these circumstances, when the new streamgage location uses the same control, little if any change to the rating is to be expected. Otherwise, changes to the rating after the move are unsurprising, and comparing ratings from before and after the move provides no information on rating stability. Not only that, but when a streamgage is moved somewhere with a different control, standard procedure is to stop publishing preliminary flow data to the web until the new rating has been established, which generally takes several months.

Three streamgages were moved to new gaging pools during water years 2013 (table 11). Two of these moves, for

Table 10.   Locations, magnitudes, and dates of datum changes for streamgages in Virginia, water years 1990–2013.

[VA, Virginia]

Streamgage number	Streamgage name	Magnitude of datum change, in feet	Date of datum change
02011460	Back Creek near Sunrise, VA	2.00	10/28/2008
02027000	Tye River near Lovingston, VA	2.00	9/3/2004
02027500	Piney River at Piney River, VA	3.00	11/3/2009
02061500	Big Otter River near Evington, VA	2.00	6/9/2005
02077000	Banister River at Halifax, VA	3.00	9/24/2002
02047500	Blackwater River near Dendron, VA	30.99	11/28/2012

01615000, Opequon Creek near Berryville, and 01662800, Battle Run near Laurel Mills, coincided with discontinuation of the streamgage. The third, 01668000, Rappahannock River near Fredericksburg, was moved to a new gaging pool in March 2001 owing to safety and access concerns. Values of Q_{same} were deleted for the period between the streamgage move and the next flow measurement, and values of Q_{prev} were deleted until the subsequent flow measurement.

Suspension of Streamgage Operations

When streamgages are discontinued but later reactivated, the old rating remains in the database and might be used as a temporary rating to generate provisional data while measurements are being made either to verify it or to generate a new rating. These provisional data would not ordinarily be published to the web before the rating was verified, so a comparison between the old rating and the updated rating would ordinarily not be useful.

Eighteen streamgages were discontinued for 30 days or longer, but were later reactivated, during water years 1991–2013 (table 12). For eight of these streamgages, the hiatus came before the earliest valid AltFlow date (varying by site; the earliest date at which two flow measurements had been made after shifts and ratings began to be stored in the database).

For the 10 streamgages for which the hiatus came during a period with potentially valid AltFlows, the AltFlow daily values were not computed using the pre-hiatus rating. Q_{prev} values were resumed once two flow measurements had been made following the hiatus.

Estimated and Qualified Daily Flows

As discussed previously, at times when stage record is missing or in error, daily values are estimated. Errors in stage record may be caused by instrument failure, sediment deposition on the intake or orifice, or ice effect. Estimates may be based on partial record at the streamgage being estimated or on hydrographic comparison with nearby streamgages known to be correlated with the streamgage being estimated. Weather records are checked for rain or freezing temperatures.

A critical issue for purposes of this study is that daily flow values may be estimated without any use of the streamgage's rating. Nearly as important, if flow is to be estimated for a small amount of record and limited to part of the hydrograph where a shift might be needed if flow were to be computed, the need for a shift is moot. These factors represent limitations of the AltFlow approach, and AltFlows have little relevance for periods of estimated records.

The total percentage of estimated days at a streamgage may be a reasonable surrogate for quality of the stage record. For days when AltFlow record was developed, 4 percent of the overall record combined from all streamgages was estimated. Ten percent or more of the overall record was estimated for seven sites (01643805, North Fork Goose Creek at Route 729 near Lincoln; 02032250, Moormans River near Free Union; 02079640, Allen Creek near Boydton; 01660400, Aquia Creek near Garrisonville; 01616100, Dry Marsh Run near Berryville; 01654000, Accotink Creek near Annandale; and 02040000, Appomattox River at Mattoax; table 13, at end of report).

The number of estimated days during the winter may be a fair surrogate for the amount of ice effect at a streamgage, in particular for streams where little record is estimated during other seasons (table 13). For the entire network during water years 1991–2013, 7 percent of the overall winter record (December, January, and February) was estimated. January was the month with the greatest rate of estimated record, and 28 percent of the overall estimated days were during January. At 5 streamgages, 20 percent or more of winter record was estimated; 10 percent or more of winter record was estimated at 54 streamgages. Most streamgages with a high rate of estimated record during the winter were at high elevations or had small drainage areas. At 26 streamgages, 1 percent or less of winter record was estimated; at 14 of those, 0 percent of winter record was estimated. Most of these streamgages were on large rivers, directly downstream from dams, or had a short period of record.

At one site (02077000, Banister River at Halifax, VA) daily flows were estimated on 230 days from 1999 through 2002 because valid stage measurements were not available. Estimates were based on hydrographic comparison with other streamgages. This happened on days when the gage height was missing because stage was low enough that the stilling-well intake was out of the water. These days also lack a value for Q_{prev}, even though apparently valid previous ratings exist. Because the original stage record was missing,

Table 11. Streamgages that were moved to new gaging pools, and dates of the move, in Virginia, water years 1991–2013.

[Gages that were moved to new locations in the same gaging pool with the same control are not included; VA, Virginia]

Streamgage number	Streamgage name	Date the gage was moved
01615000	Opequon Creek near Berryville, VA	10/15/2002
01662800	Battle Run near Laurel Mills, VA	10/3/1997
01668000	Rappahannock River near Fredericksburg, VA	3/6/2001

Table 12. Virginia streamgages that were discontinued and reactivated for 30 or more consecutive days, and the dates they were discontinued and reactivated, water years 1991–2013.

[AltFlow, alternative flow tables; VA, Virginia]

Streamgage number	Streamgage name	Date discontinued	Date reactivated	Date AltFlow resumed
01615000	Opequon Creek near Berryville, VA	10/19/1997	10/1/2002	12/10/2002
01626850	South River near Dooms, VA	12/10/1996	7/21/2005	10/14/2005
01643700	Goose Creek near Middleburg, VA	1/28/1997	6/28/2001	No lost AltFlow record; no valid AltFlows from before hiatus
01660400	Aquia Creek near Garrisonville, VA	10/15/1997	11/4/1999	No lost AltFlow record; no valid AltFlows from before hiatus
01662800	Battle Run near Laurel Mills, VA	7/10/1995	10/1/1997	10/30/1997
01663500	Hazel River at Rixeyville, VA	10/12/1992	10/1/2001	No lost AltFlow record; no valid AltFlows from before hiatus
01665500	Rapidan River near Ruckersville, VA	6/30/1995	10/1/1998	No lost AltFlow record; no valid AltFlows from before hiatus
01670400	North Anna River near Partlow, VA	9/30/1995	3/27/2007	5/1/2007
01671100	Little River near Doswell, VA	9/30/1999	9/22/2000	No lost AltFlow record; no valid AltFlows from before hiatus
01672500	South Anna River near Ashland, VA	9/30/1997	6/28/2003	7/17/2003
02020500	Calfpasture River above Mill Creek at Goshen, VA	9/30/1996	10/1/1998	No lost AltFlow record; no valid AltFlows from before hiatus
02030000	Hardware River below Briery Run near Scottsville, VA	10/10/1995	10/1/1996	No lost AltFlow record; no valid AltFlows from before hiatus
02030500	Slate River near Arvonia, VA	10/15/1995	6/23/2005	8/2/2005
02032250	Moormans River near Free Union, VA	9/30/1997	7/7/2005	No lost AltFlow record; no valid AltFlows from before hiatus
02077000	Banister River at Halifax, VA	11/10/2011	3/1/2012	3/25/2012
02079640	Allen Creek near Boydton, VA	10/20/1996	10/1/2000	11/29/2000
03175500	Wolf Creek near Narrows, VA	9/30/1995	10/1/1996	11/12/1996
03177710	Bluestone River at Falls Mills, VA	4/27/1997	9/22/2004	12/8/2004

the hydrographer had no practical reason to develop a rating for that range of stage, and therefore there was no defined gage height that corresponded to the daily flows for those days. This ended in September 2002, when the stilling well was replaced with a bubbler system that could measure lower stage values, and the datum was changed.

Retrievals of daily flow values include, by default, a column of qualifiers. The qualifier for estimated flows (A:e) is one of these. Two other qualifiers were common. The first and by far the most common is A, for approved, indicating that flows were computed in the usual way. The second is A:1, which is described in comment fields as indicating that daily flow values are write-protected without any remark code to be printed. What this typically means in practice is that for some reason, the stage recorder collected a partial day of record while flow was stable, and the mean daily flow computed from available values was judged to characterize the day.

Unit values would have been recorded under a different data descriptor (DD), and particularly early in the 1990s, they may have been processed under that DD and entered manually into the daily flow table. In such cases, these values might potentially have been developed from a different rating than the one used for the development of AltFlows. These values represent less than one-half a percent of the total record for which AltFlows were developed.

Days of Zero Flow

An observation of zero flow can be associated with more than one gage height; once flow decreases to zero, the stage of the gaging pool can continue to decrease as flow remains zero. On days when AltFlows were calculated, Q_{meas} was observed a total of 2,620 days at 26 streamgages (table 14). At four sites, zero flow was observed 100 or more times, with a maximum

Table 14. Number of days with zero flow for streamgages in Virginia, water years 1991–2013.

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Days of zero flow
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	28
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	110
01643700	Goose Creek near Middleburg, VA	52
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	196
01645704	Difficult Run above Fox Lake near Fairfax, VA	6
01654000	Accotink Creek near Annandale, VA	14
01656000	Cedar Run near Catlett, VA	4
01658500	South Fork Quantico Creek near Independent Hill, VA	51
01660400	Aquia Creek near Garrisonville, VA	1
01662800	Battle Run near Laurel Mills, VA	1
01669000	Piscataway Creek near Tappahannock, VA	24
01669520	Dragon Swamp at Mascot, VA	56
01673550	Totopotomoy Creek near Studley, VA	35
01673800	Po River near Spotsylvania, VA	8
01674000	Mattaponi River near Bowling Green, VA	72
02030000	Hardware River below Briery Run near Scottsville, VA	1
02031000	Mechums River near White Hall, VA	26
02032250	Moormans River near Free Union, VA	5
02037000	James River And Kanawha Canal near Richmond, VA	775
02041000	Deep Creek near Mannboro, VA	4
02046000	Stony Creek near Dinwiddie, VA	3
02047500	Blackwater River near Dendron, VA	972
02049500	Blackwater River near Franklin, VA	12
02051000	North Meherrin River near Lunenburg, VA	5
02065500	Cub Creek at Phenix, VA	1
02079640	Allen Creek near Boydton, VA	158
	Total	2,620

of 972 days of zero flow at 02047500, Blackwater River near Dendron.

Because an observation of zero flow is of particular concern to water managers interested in knowing the reliability of provisional flow during low-flow periods, these observations were all retained, and Q_{same} and Q_{prev} were computed for them, despite some ambiguity in back calculating their gage heights.

Q_{same} and Q_{prev} were not always zero on the same dates. Values of zero flow for Q_{same} were computed on 697 days when Q_{prev} had flows at 13 sites (table 15). At these sites, mean values of Q_{prev} ranged from 0.01 ft³/s to 136 ft³/s. Values of zero flow for Q_{prev} were computed on 1,023 days when Q_{same} had flows at 19 sites (table 16). At these sites, mean values of Q_{prev} ranged from 0.01 ft³/s to 87.6 ft³/s. For both of these characteristics, the same site (02037000, James River and Kanawha Canal near Richmond, VA) had the maximum value when a zero value was observed for the other characteristic.

Previously Undefined Ratings

One of the circumstances for which Q_{prev} could not be computed when a valid previous rating was available was when stage entered a range where it was undefined in the previous rating. This happened for two different reasons, either (1) scour to the control, which resulted in ordinary flows becoming associated with unprecedented low stage, or (2) flows were higher or lower than had previously been measured.

One fairly common scenario concerning undefined ratings was where the control scoured to an elevation lower than previously defined in the rating. When this happens, the streamgage's real-time page displays a clearly labeled red line showing the minimum plausible limit of the rating as designated by the field office. Preliminary flow data lower than this threshold are not published to the web, and an explanation is provided on the real-time page. In this retrospective analysis, however, these scour events resulted in periods during which a valid previous rating had been in effect but Q_{prev} was missing.

While not necessarily more problematic than any other undefined ratings for real-time flow data users, ratings for which zero flow was undefined were a complication for computing Q_{prev}. If the previous rating included a gage height at which flow was zero, flow remained zero for all lower gage heights, so that strictly speaking, the value of these gage heights was defined. If the minimum defined flow was greater than zero, then Q_{prev} represented a non-detect. The lowest defined flow represented a detection limit, and flows lower than that were known only to be lower than the detection limit. Water-quality analysts frequently work with concentration data that represent quantification at less than a detection limit and do so using a variety of approaches, all of which have some advantages but none of which is completely satisfactory for all purposes (Helsel and Hirsch, 2002). For purposes of this analysis, the Q_{prev} values that were less than a nonzero threshold were arbitrarily set equal to the minimum flow value defined in the relevant rating—the detection limit—because VDEQ water managers determined the most likely guidance that they would give holders of withdrawal permits who asked about missing values in this circumstance would be to assume flow was equal to the last posted value until new flow values

Table 15. Number of days when Q_{same} equaled zero but Q_{prev} did not, and mean and maximum values of Q_{prev} for those days for streamgages in Virginia, water years 1991–2013.

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value; ft³/s, cubic feet per second; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of days when $Q_{same} = 0$, but Q_{prev} did not	Mean of Q_{prev} on those days (ft³/s)	Maximum of Q_{prev} on those days (ft³/s)
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	69	0.04	0.21
01643700	Goose Creek near Middleburg, VA	52	3.90	3.90
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	63	16.9	19.0
01654000	Accotink Creek near Annandale, VA	2	0.01	0.01
01656000	Cedar Run near Catlett, VA	7	0.05	0.05
01658500	South Fork Quantico Creek near Independent Hill, VA	17	0.16	0.27
01660400	Aquia Creek near Garrisonville, VA	2	0.14	0.14
01669000	Piscataway Creek near Tappahannock, VA	24	2.50	2.50
01669520	Dragon Swamp at Mascot, VA	11	0.64	0.64
02037000	James River And Kanawha Canal near Richmond, VA	291	136	643
02047500	Blackwater River near Dendron, VA	143	0.36	0.83
02051000	North Meherrin River near Lunenburg, VA	3	0.08	0.08
02079640	Allen Creek near Boydton, VA	13	2.48	9.50

Table 16. Number of days when Q_{prev} equaled zero but Q_{same} did not, with mean and maximum values of Q_{prev} for those days for streamgages in Virginia, water years 1991–2013.

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value; =, equals; ft³/s, cubic feet per second; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of days when Q_{same} = 0, but Q_{prev} did not	Mean of Q_{prev} on those days (ft³/s)	Maximum of Q_{prev} on those days (ft³/s)
01620500	North River near Stokesville, VA	43	16.3	43.0
01632900	Smith Creek near New Market, VA	37	16.4	38.0
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	5	0.38	0.58
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	87	0.98	2.70
01645704	Difficult Run above Fox Lake near Fairfax, VA	7	0.44	0.50
01654000	Accotink Creek near Annandale, VA	16	3.79	6.70
01658500	South Fork Quantico Creek near Independent Hill, VA	135	2.10	5.30
01669000	Piscataway Creek near Tappahannock, VA	4	0.56	0.64
01673800	Po River near Spotsylvania, VA	19	0.03	0.08
01674000	Mattaponi River near Bowling Green, VA	231	13.8	55.0
02030000	Hardware River below Briery Run near Scottsville, VA	8	0.01	0.01
02032250	Moormans River near Free Union, VA	6	0.02	0.02
02036500	Fine Creek at Fine Creek Mills, VA	12	0.13	0.49
02037000	James River And Kanawha Canal near Richmond, VA	90	87.6	114
02038850	Holiday Creek near Andersonville, VA	6	0.04	0.06
02046000	Stony Creek near Dinwiddie, VA	44	1.72	4.9
02047500	Blackwater River near Dendron, VA	45	29.2	73.0
02051000	North Meherrin River near Lunenburg, VA	6	0.11	0.15
02079640	Allen Creek near Boydton, VA	222	3.38	28.0

appear on the web (Scott Kudlas, Virginia Department of Environmental Quality, oral commun., October 2015). During water years 1991–2013, there were 1,330 days of record with undefined Q_{prev} values but with a valid previous rating; these occurred for 57 sites and include 220 discrete incidents (table 17).

A different scenario of an undefined range of a valid previous rating that also resulted in a missing Q_{prev} was when flows were first measured that were either higher or lower than any previous flow. Flows higher than the maximum flow defined in previous ratings were rare and affected only 6 days of AltFlow records. One day each at three sites (01644280, Broad Run near Leesburg; 02040892, Appomattox River at Route 602 near Mannboro; and 02049500, Blackwater River near Franklin) and 3 days at another site (02047500, Blackwater River near Dendron, estimated values in a flood during September 1999) were adjusted to account for flows higher than previously encountered. New low flows of record were more common during the study period and affected more AltFlow record. When flows reached new lows, they typically remained low for several days. Undefined ratings caused by scour represent an important type of instability, whereas undefined ratings caused by higher or lower flows than had

previously been encountered are (1) less likely to recur and (2) don't represent instability at all, just the first time a particular set of hydrologic conditions were recorded at a streamgage. There were 37 days of record at 15 sites with undefined ratings, on which flows were lower than they had been since October 1, 1990, the beginning of the study period (table 17). These seem likely to represent cases when the rating was undefined because flows reached new lows, rather than because the control scoured.

A different scenario involving undefined ratings is that, for a few sites, approved daily values were less than the minimum flow defined in the expanded shifted rating presumably used to compute the flow value (table 18). This happened on 249 days at nine sites. Nine of these 249 values were estimated, so these values may have been computed through hydrographic comparison. The other 240 values possibly were computed using stage measurements from a backup recorder outside the default DD for flow using a rating for that DD, then written as unit flow values. In any case, the 240 values do not correspond to any rating available for analysis, and their presence resulted in an error in Microsoft Excel. For all 249, Q_{prev} and Q_{same} were deleted from their respective rows, and comments were added explaining the deletion.

Table 17.   Number of times ratings entered ranges that had been undefined in the previous actual rating and set equal to the defined rating minimum for the purpose of this analysis, and number of days they were in such ranges for streamgages in Virginia, water years 1991–2013.

[AltFlow, alternative flow tables; Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Days of AltFlow record based on previously undefined ratings	Number of discrete incidents when Q_{prev} could not be computed because the previous rating was undefined	Number of days with undefined previous ratings that were new record low flows since October 1, 1990
01613900	Hogue Creek near Hayfield, VA	18	2	
01615000	Opequon Creek near Berryville, VA	5	5	2
01621050	Muddy Creek at Mount Clinton, VA	117	10	
01626850	South River near Dooms, VA	67	7	
01628500	South Fork Shenandoah River near Lynnwood, VA	6	1	3
01632000	North Fork Shenandoah River at Cootes Store, VA	21	5	
01643700	Goose Creek near Middleburg, VA	2	1	
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	24	4	
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	25	3	
01644280	Broad Run near Leesburg, VA	1	1	
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	9	2	
01646305	Dead Run at Whann Avenue near Mclean, VA	1	1	
01652500	Fourmile Run at Alexandria, VA	3	3	
01653000	Cameron Run at Alexandria, VA	93	27	3
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	36	10	
01658500	South Fork Quantico Creek near Independent Hill, VA	70	9	
01660400	Aquia Creek near Garrisonville, VA	22	1	
01662800	Battle Run near Laurel Mills, VA	43	5	
01663500	Hazel River at Rixeyville, VA	4	2	
01664000	Rappahannock River at Remington, VA	29	4	
01666500	Robinson River near Locust Dale, VA	42	5	3
01667500	Rapidan River near Culpeper, VA	1	1	1
01668000	Rappahannock River near Fredericksburg, VA	13	1	
01671025	North Anna River above Little River near Doswell, VA	9	9	
01673550	Totopotomoy Creek near Studley, VA	16	2	
01673800	Po River near Spotsylvania, VA	38	7	
01674000	Mattaponi River near Bowling Green, VA	82	9	5
01674500	Mattaponi River near Beulahville, VA	11	2	8
02011460	Back Creek near Sunrise, VA	2	1	
02013000	Dunlap Creek near Covington, VA	42	3	
02014000	Potts Creek near Covington, VA	10	2	
02022500	Kerrs Creek near Lexington, VA	58	4	
02024915	Pedlar River at Forest Road near Buena Vista, VA	11	3	1
02032250	Moormans River near Free Union, VA	1	1	1
02032640	North Fork Rivanna River near Earlysville, VA	7	1	
02040892	Appomattox River at Route 602 near Mannboro, VA	1	1	
02041000	Deep Creek near Mannboro, VA	1	1	
02041650	Appomattox River at Matoaca, VA	7	1	0
02042500	Chickahominy River near Providence Forge, VA	26	9	0
02045500	Nottoway River near Stony Creek, VA	10	2	3

Table 17. Number of times ratings entered ranges that had been undefined in the previous actual rating and set equal to the defined rating minimum for the purpose of this analysis, and number of days they were in such ranges for streamgages in Virginia, water years 1991–2013.—Continued

[AltFlow, alternative flow tables; Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Days of AltFlow record based on previously undefined ratings	Number of discrete incidents when Q_{prev} could not be computed because the previous rating was undefined	Number of days with undefined previous ratings that were new record low flows since October 1, 1990
02046000	Stony Creek near Dinwiddie, VA	31	7	0
02047500	Blackwater River near Dendron, VA	41	4	0
02052000	Meherrin River at Emporia, VA	18	1	0
02061000	Big Otter River near Bedford, VA	10	1	1
02062500	Roanoke (Staunton) River at Brookneal, VA	69	3	0
02077000	Banister River at Halifax, VA	9	8	0
02077500	Hyco River near Denniston, VA	2	1	2
02079640	Allen Creek near Boydton, VA	1	1	0
03170000	Little River at Graysontown, VA	10	1	0
03173000	Walker Creek at Bane, VA	2	1	0
03176500	New River at Glen Lyn, VA	1	1	0
03177710	Bluestone River at Falls Mills, VA	7	2	2
03207800	Levisa Fork at Big Rock, VA	1	1	0
03208950	Cranes Nest River near Clintwood, VA	45	6	0
03473000	South Fork Holston River near Damascus, VA	27	7	1
03478400	Beaver Creek at Bristol, VA	66	6	1
03531500	Powell River near Jonesville, VA	6	1	0
	Total	1,330	220	37

Table 18. Days of approved flow record less than their respective rating minima for streamgages in Virginia, water years 1991–2013.

[VA, Virginia]

Streamgage number	Streamgage name	Days computed	Days estimated	Total days
02031000	Mechums River near White Hall, VA	52	6	58
02041000	Deep Creek near Mannboro, VA	1	0	1
02041650	Appomattox River at Matoaca, VA	4	0	4
02042500	Chickahominy River near Providence Forge, VA	18	0	18
02047000	Nottoway River near Sebrell, VA	0	3	3
02047500	Blackwater River near Dendron, VA	156	0	156
01643700	Goose Creek near Middleburg, VA	5	0	5
01656000	Cedar Run near Catlett, VA	1	0	1
03473000	South Fork Holston River near Damascus, VA	3	0	3
	Total	240	9	249

Unusual Sites

At streamgage 02037000, James River and Kanawha Canal near Richmond, VA, flow is challenging to measure using ordinary methods. The accuracy of flow records from the canal is questionable, especially low-flow records. It has a low gradient and extreme rating changes. The manuscript in Annual Water-Data Reports and Water-Year Summaries for this site includes the qualifying statement "Canal diverts from James River 1,200 ft upstream from Bosher Dam and discharges into river at several points downstream from gaging station near Richmond. Beginning with the 1969 water year, the descriptive statement that above 2,540 ft³/s, gage height, 14.5 ft, there is interchange of flow with the James River and that discharge above 2,540 ft³/s is included in discharge for the James River near Richmond (streamgage 02037500) has been used. Daily discharges in excess of 2,540 ft³/s for water years 1937–68 should be used with caution until historical records of canal construction and modifications can be reviewed. Figures given show flow in canal only" (U.S. Geological Survey, 2017).

The site 02047500, Blackwater River at Dendron, VA, is a problematic site. It is affected by variable backwater, and hydrographers described this site as subject to frequent beaver activity. Issues were exhibited through all the lines of evidence examined in this study. Measurements plotted far to the left of their ratings at irregular but recurrent intervals, indicating the effect of some type of backwater. These backwater-affected measurements generally lined up with each other as a second ghost line on the long-term rating plot. Ratings also shifted by several feet from time to time, resulting in AltFlows computed from previous ratings that were undefined on the low end one time and on the high end the next. The ratings and measurements for this site were reviewed for some sort of processing artifact during the course of this study; the review found that the ratings and measurements accurately reflected the values stored in NWIS.

The site 01671025, North Anna River above Little River near Doswell, VA, is a continuous partial-record site. At this site, flow is not computed when stage is above 12.0 feet. This results in many short gaps in the flow record and limits the number of flow statistics that can be computed from this site's record. Although this site was included in most analyses in this study, the partial nature of its record prevented it from being included in others.

Comparison of Ratings and Measurements as a Check on Rating Compilation

Comparing flow measurements to expanded shifted ratings retrieved for the time of the measurement shows how often hydrographers develop ratings within the stated guidelines (Rantz and others, 1982). For a measurement rated Good by the hydrographer, a shift or rating is to be developed within 5 percent of the measurement. For a measurement rated Fair, the rating is to be within 8 percent, and only if a measurement

is rated Poor is the rating to be left with a greater than 8 percent difference. Hydrographers may also decide in the field or the office that a measurement was faulty; such a measurement may be disregarded (not used in working the record) or, in a less extreme case, effectively downgraded to Fair or Poor in the office (not given full weight). In such cases, however, appropriate remarks are to be entered into the database.

Expanded shifted ratings and the flow measurements from which they were developed were compared to each other and to the criteria used for determining whether to develop a shift (table 19, at end of report). Overall, 20,380 measurement-rating pairs were compared. Measurements with negative flows were not included in this analysis, although measurements with zero flow were. For 2,482 of these, the measurement was more than 5 percent but less than 8 percent different from the rating, and for 1,063 of these, the measurement was 8 percent or greater different from the rating. The criteria of 5 and 8 percent are thresholds mandated in USGS methods manuals at which flow measurements are rated as Poor and Fair, respectively; if measurements are rated Good, the rating is to be developed or shifted to within 5 percent of the flow, if the measurement is rated Fair, the rating is to be within 8 percent, and only if a measurement is rated Poor is the rating allowed to diverge more than 8 percent from the measurement (Rantz and others, 1982; Turnipseed and Sauer, 2010).

Measurement quality assessments have always accounted for factors including flow distribution in the section, turbulence, bed roughness, changes in flow during the measurement, and equipment malfunctions. The hydrographer has always been expected to determine the departure between the measurement and the rating in the field immediately after the measurement, and to explain and document it relative to control conditions, flow measurement quality, and less frequently, stage measurement quality. In practice, problems with measurements are sometimes discovered in the office; when this happens, the database is to be updated to include remarks describing the problem.

The overall rate of unexplained measurement-rating divergence was 3.6 percent. To be counted as divergent, a measurement rated Good diverged more than 5 percent from the shifted rating or a measurement rated Fair diverged more than 8 percent from the shifted rating; measurements rated Poor were not counted. However, at seven sites, the rate of unexplained divergence was greater than 10 percent, and the maximum rate was 18 percent. For these sites, the retrievals of both ratings and measurements were checked and verified.

The percentage of unexplained measurement-rating divergence was essentially uncorrelated among sites with other stability metrics. However, several of the sites with the lowest rates of unexplained divergence were among the most stable sites as shown by R^2 of GAMs or any of the AltFlow error terms (table 20, available online). One potential explanation for high rates of unexplained measurement-rating divergence at some sites could be that, if the stage record was poor at the site and large amounts of record would have to be estimated, there would be little practical reason to develop shifts at the

site. However, it was particularly poorly correlated with percentage of estimated days ($R^2 = 0.0085$), which does not support this idea. Another possible explanation is that, at some of these sites, the daily value record itself was judged to be Fair or Poor in the qualitative assessments that are published in Annual Water-Data Report remarks for each streamgage (U.S. Geological Survey, 2016b). Although hydrographers often consider these assessments to be a major part of working a flow record, the assessments are not captured in NWIS.

Examples of AltFlow Hydrographs

All AltFlows are plotted in a series of hydrographs for the period of record in appendix 4. In total, more than 2,620 streamgage years of AltFlow record were developed at the 174 streamgages in the study (table 21, at end of report). Total length of AltFlow record ranged from 71 days through 8,387 days.

Hydrographs for four selected streamgages in the Shenandoah River Basin are shown as examples of several patterns that appear in these hydrographs (plate 3). First, although the period of record differs among streamgages, one site (01628500, South Fork Shenandoah River near Lynnwood, VA) has a nearly complete record owing to the availability of historical shifts and ratings since the 1991 water year. For the other three streamgages (01620500, North River near Stokesville; 01629500, South Fork Shenandoah River near Luray; and 01631000, South Fork Shenandoah River at Front Royal) AltFlow periods of record began in 2002, even though flow daily values are available continuously throughout the entire study period. All hydrographs are shown on the same time scale to simplify comparison among sites for simultaneous events. Values of Q_{same} and Q_{prev} are shown in units of $\log_{10}$ of flow in ft³/s; negative values on the plots reflect values of flow between 0 and 1 ft³/s. Values of zero flow are undefinable on these plots and are shown as lines that drop to the bottom of the scale.

At all sites, Q_{same} becomes available before Q_{prev}. Differences in Q_{same} and Q_{prev} are straightforward to identify as the parts of the plot where the two lines separate. At most sites, differences are greatest and most common at low or medium-low flows. At all sites, differences are more pronounced in some years than others. At one of the sites (01620500, North River near Stokesville), Q_{prev} went to zero, although Q_{same} did not, indicating a fairly large change that was probably the result of scour. This same site also showed differences in Q_{same} and Q_{prev} at medium and high flows, which are unlikely without scour and fill on the control. In contrast, at the sites where differences appear only at low flows, the shifts and rating changes could be the result of algae and macrophyte growth or leaf accumulation. These observations are consistent with site descriptions (table 8).

Dates of measurements are shown as green dots plotted at the minimum observed value of Q_{same} (plate 3). These are the dates when Q_{same} and Q_{prev} diverge from each other,

or when the lines representing them cross on the plot. The AltFlow changes represent snapshots on the dates of flow measurements. Large changes, particularly at low flows at sites where shifting is caused by algae and macrophyte growth, were not necessarily as abrupt as they are depicted in these plots and were probably prorated through time from magnitudes of zero to the value that was in effect when the measurement was made. Likewise, at sites where shifting is done to account for plant growth, measurements may or may not have been made when shifts were at their maxima, and there is no particular reason to think that the AltFlows and the hydrographs derived from them capture maximum shifts very often.

Stability Metrics and Their Relations to Each Other and to Basin Characteristics

The set of AltFlow data was large and complex enough that no single metric summarized it completely. Several different summary metrics were computed, and they describe different aspects of rating stability. Additionally, other metrics of rating stability were considered, including average number of days that base ratings remained in effect, R^2 from the GAM models of flow measurements, percentages of winter and total days estimated, and percentage of measurements at a site with unexplained divergence from the expanded shifted rating in effect when the measurement was made. These metrics have different strengths and weaknesses. Some of them are clearly meaningful, whereas others appear not to be. The latter group is discussed to show that the metrics were, in fact, considered and examined. Because different aspects of rating stability could be relevant to management and planning actions, overall totals of these stability metrics are compiled into a color-coded, sortable table (table 20).

Description of Stability Metrics

Fifteen stability metrics were considered. One was derived from hydrographer stability ratings, 7 were computed from AltFlows, and 7 were computed from other data.

Stability Class

1. Stability class, as described by hydrographers, was metric 1 (table 22, at end of report); it was used for verification and as a basis of comparison for all the other metrics. Senior hydrographers participated in interviews, and later were presented with questionnaires and asked to rate the control stability for all the streamgages they personally were familiar with as Excellent, Good, Fair, or Poor. (Instructions for the questionnaire are given

in table 23.) The descriptive evaluations were converted to numeric values of 4, 3, 2, and 1, respectively, and averaged. Ten senior hydrographers answered the questionnaire.

A total of 397 assessments were received. Considering all assessments for all sites, 32 were Excellent, 220 were Good, 109 were Fair, and 36 were Poor. Average scores for sites ranged from 1 to 4. Most (112) sites were assessed by 2 different hydrographers; 13 sites were assessed by only 1 hydrographer, 31 were assessed by 3 hydrographers, 13 sites were assessed by 4 hydrographers, and 3 sites were assessed by 5 hydrographers. Of the 47 sites with 3 or more assessments,

hydrographers came to a consensus on stability for 16 of them. Of the 112 sites with two assessments, the two hydrographers agreed for 47 of them. At 15 sites, hydrographers differed in their assessments by a full stability class, meaning that at least one hydrographer considered the site in question Excellent, and at least one other hydrographer considered it Fair, or one considered the site Good, and another considered it Poor. There were no sites that one hydrographer considered Excellent but another one considered Poor.

Hydrographers who independently evaluated the same streamgages gave them different scores and ranked them differently. Some hydrographers had more positive or negative assessments overall than others; some individuals considered

Table 23.   Instructions to senior hydrographers for answering a control and rating stability questionnaire, for Virginia streamgages active September 30, 2013.

[Assessments made on the basis of these responses are given in table 22. Descriptions of control and rating stability classes are in **bold type**.]

The answers for this questionnaire are to be used to classify selected streamgages in Virginia on the basis of overall control stability and rating quality, particularly with respect to how reliable provisional data are in real time and how likely provisional data are to match final data at each site. Please consider factors including frequency of shifting, magnitude of shifts or rating changes needed, predictability of changes, duration of stable periods, quality of the measuring section, site characteristics that affect the completeness and quality of stage data, or anything else that affects the likelihood of changes from provisional data to final data.

Please provide an answer for each streamgage that you're familiar with, and skip streamgages you're not familiar with. Because several stream characteristics of interest are related to location, some field offices will have many good or excellent sites and few fair or poor sites, while other field offices will have many fair or poor sites and few good or excellent sites. There is no particular reason that the overall network would be divided equally into excellent, good, fair, and poor sites, so don't worry about having more in one category than another. Different people have different expectations for excellent, good, fair, and poor sites, but because common criteria are desirable for this questionnaire, please consider the following criteria.

An <u>excellent site</u> is one where the base rating is well defined, may remain stable for years, and is only likely to change in response to a major event. Shifts are small and are made in response to predictable seasonal factors. Scour and fill on the control is rare or minor. Some record may be affected by ice, but if so, it is easy to identify in real time.	**A <u>good site</u> is one where the base rating is well defined, but it may change every few years. It might be subject to regular seasonal shifting because of weeds, algae, or leaves, but the shifts are moderate, predictable, and practical to define. Alternately, it might have occasional or moderate scour-fill shifting.**
A <u>fair site</u> is one where the rating changes fairly frequently. The control may have fairly large weed or leaf shifts, which may sometimes be difficult to characterize throughout the full range of stage. It may have substantial scour-fill shifting, or scour and fill of the control occasionally may be large. The stream bank may only be moderately stable, and occasionally a tree or other obstruction may catch on the control. Beavers may occasionally be present, but they do not tend to build dams on the gage control very often.	**A <u>poor site</u> may be one where the control changes constantly. The base rating may not be practical to define because of frequent changes to the control. Alternately, the control may not change extraordinarily often, but the changes are large and unpredictable. The control may scour and fill multiple times between visits. Banks may be highly unstable, and this may result in logs catching on the control frequently and washing off between visits. The timing of these events may be difficult to determine after the fact. Beavers may build dams on the control frequently.**

most of the controls to be Fair or Poor and few to be Excellent, whereas others considered many of their controls to be Good or Fair and few to be Poor.

Some of the inconsistency of evaluations was likely the result of changes to streams through time; individuals who worked at the same streamgages at different times experienced different conditions and were left with different impressions. Another cause of inconsistent evaluations was lack of a common frame of reference. No individual hydrographer in Virginia claimed to be familiar with every streamgage in the network. Of the 174 streamgages included in this study, the most that any individual evaluated was 100. However, as shown by the lack of agreement on stability of controls rated by more than one hydrographer, different individuals, even experts, are prone to make subjective assessments differently.

Despite these weaknesses, this metric alone might be acceptable for certain applications, such as internal allocation of workload within a field office. It was used as verification for the quantitative metrics discussed below. Consistency in subjective assessments of the stability of controls is not essential to consistent computation of flow data, which instead requires consistent responses to measured changes regardless of whether or not a particular streambed is stable.

Metrics Derived from AltFlows

The AltFlow tables are summarized using seven different stability metrics.

2.   The average of daily percent errors, or

$$\frac{\sum\limits_{i}^{n} \dfrac{Q_{prev} - Q_{same}}{Q_{same}}}{n} . \qquad (1)$$

This method for computing percent error works well for datasets with small error terms. However, it is problematic when error as a percentage of Q_{same} is relatively large. Error terms have larger magnitudes when Q_{same} is greater than (>) Q_{prev} than when $Q_{prev} > Q_{same}$. This is because the magnitude of error as a percentage of Q_{same} is asymptotic as it approaches 100 percent when $Q_{same} > Q_{prev}$ but unlimited when $Q_{prev} > Q_{same}$. When the difference between Q_{prev} and Q_{same} exceeds the magnitude of flow, daily percent error is wildly different, depending on whether $Q_{prev} > Q_{same}$ or $Q_{same} > Q_{prev}$. When these values are averaged together, values for days when $Q_{same} > Q_{prev}$ dominate values when $Q_{prev} > Q_{same}$. Rating changes that exceed the magnitude of flow are not especially common overall (they represent 1.3 percent of observations in the overall dataset), but they are common at some sites (table 20). At streamgage 02037000, James River and Kanawha Canal near Richmond, VA, the absolute value of $Q_{prev} - Q_{same}$ exceeded that day's Q_{same} on 21.5 percent of days, and at streamgage 01646305,

Dead Run at Whann Avenue near McLean, VA, the absolute value of $Q_{prev} - Q_{same}$ exceeded that day's Q_{same} on 19.5 percent of days. Three more sites had differences exceeding Q_{same} more than 10 percent of the time, and 11 sites had differences exceeding Q_{same} between 5 and 10 percent of the time. Similar but nonidentical patterns were present when error was compared to Q_{prev}. The same two sites (02037000 and 01646305) had the highest percentages of difference exceeding flow and had more than 10 percent of days when difference exceeded flow. Nine instead of 11 sites had between 5 and 10 percent of days when differences exceeded Q_{prev}.

Another, albeit smaller, problem with the average of daily errors as a metric is that, when the value of Q_{same} is zero but flow is indicated for Q_{prev}, values for error expressed as a percent of Q_{same} are undefined. This happened at 13 sites in the network and affected 697 days of record (table 15). Forty-two percent of these days came at one site, 02037000, James River and Kanawha Canal near Richmond, VA. The largest of these non-zero values of Q_{prev} on days with Q_{same} of 0.00 were also observed at this site; mean and maximum were 136 and 643 ft³/s, respectively. At the other sites on days with Q_{same} of 0.00 but non-zero values of Q_{prev}, mean values of Q_{prev} by site ranged from 0.01 to 16.9 ft³/s, and maximums ranged from 0.01 to 19 ft³/s. For purposes of computing mean percentage error, these values were excluded, but as these values all, by definition, came at low flow, their exclusion removed valuable information from the analysis.

Problems with computation aside, this metric (average of daily percent errors) is highly sensitive to changes in ratings that affect low flows, especially the lowest flows. Differences in the lowest flows tend to be small in magnitude but high in percentage. Depending on the users' priorities and needs, this sensitivity could be useful or problematic. It is presented by month and flow percentile in table 24 (available online) and in total for each site in table 20.

3. Σ Error / ΣQ

This is a flow-weighted average of error. Positive and negative errors cancel each other out when added together so that cyclic or fluctuating rating changes, such as those caused by algae or macrophyte growth and death, leaf accumulation and removal, or scour and fill, tend to cancel each other out. To the extent that such changes are predictable, then, this metric might filter them out and quantify unpredictable rating changes. This tendency may be more meaningful for periods of 1 or 2 years than for the entire period of record. Over the entire period of record, the metric is potentially useful for determining whether a rating has changed more in one direction than another, as in the case of a stream

that has been downcutting or aggrading at a control; however, this type of change is more readily identifiable through the time-series plots of measurement residuals. It is presented in total for each site (table 20), but a more detailed table of this metric is not presented.

4. $\Sigma |Error| / \Sigma Q$

    This is a flow-weighted average of absolute error. One bias is that cyclic or fluctuating rating changes, such as those caused by algae or macrophyte growth and death, leaf accumulation and removal, or scour and fill, are counted (1) when they form and (2) when they dissipate. It is also sensitive to rating changes that affect high flows and therefore result in large changes in flow magnitude. It is presented in total for each site (table 20), but a detailed table of this metric is not presented.

5. RMSE on log-transformed flow values

    When flow data are log-transformed and RMSE is computed on the transformed data, the result is an error term that weighs errors throughout the range of flows more equally than one computed on untransformed data. One shortcoming of this is that values of zero flow, whether for Q_{prev} or Q_{same}, are undefinable for log-transformation. When both Q_{prev} and Q_{same} were equal to zero, the error term was manually set equal to zero, and the day's record was included in summary tables. RMSE is presented by month and flow percentile (table 25, available online), and in total for each site (table 20).

6. Percentage of days with zero difference between Q_{same} and Q_{prev}

    A day with no difference in flow between Q_{same} and Q_{prev} represents a point on the rating that remained the same from one visit to the next. Unlike the other stability metrics that reflect magnitude of rating change, a percentage of zero difference treats all rating changes the same. This metric therefore is not affected by whether the rating changed at high or low flow. Unlike the metrics that incorporate flow magnitude, it is not unduly affected by infrequent large changes such as those resulting from beaver dams, swimmers' dams, or human activity at otherwise stable sites; these are changes that in practice would be noticed quickly by hydrographers and water-data users.

    Total percentage of zero-difference days ranged from about15 percent (0165389205, Accotink Creek near Ranger Road at Fairfax, which has since been discontinued) to about 89 percent (02011800, Jackson River below Gathright Dam near Hot Springs, and 02011490, Little Back Creek near Sunrise; table 20). All the sites with low percentages of zero-difference days (<40 percent) were on small streams (<100-mi² drainage area)

in northern Virginia or in other parts of Virginia with elevation less than 500 feet, or both. Of the 31 sites with less than 40 percent of zero difference days, only 6 sites drained more than 100 mi², and only 3 sites were at elevations above 500 ft. In contrast, of the 30 sites where more than two-thirds of the days had zero difference, all but 4 sites were on large streams (>500 mi² drainage area) or at elevations of more than 1,000 ft, or both; 1 of the 4 sites has a bedrock control. There were many small, high-elevation sites and several large, low-elevation sites with low or medium percentages of zero difference.

The percentage of AltFlows with zero difference between Q_{prev} and Q_{same} for each streamgage in the study is shown, by month, in table 26 (available online). When zoomed out so that the entire table is visible, it displays the entire AltFlow dataset. By default, sites (rows) are sorted by downstream order number, so that they are grouped by basin. Each column represents a month. Green cells signify no or few nonzero differences between Q_{prev} and Q_{same}; stated differently, they signify little or no change in the rating from measurement to measurement. Red cells signify many nonzero differences between Q_{prev} and Q_{same} or that the rating changed between the most recent measurement and the previous measurement. While fully zoomed out, of course, dates, site identifiers, and values are illegible; the table is intended to be used interactively onscreen, zooming out to see broad patterns and zooming in to see detail.

7. Percentage of days when the difference between Q_{same} and Q_{prev} exceeded Q_{same}

    Essentially the opposite of the percentage of days with zero difference, this metric considers only large rating changes, those resulting in flow differences of 100 percent or more (table 20). Such changes existed at 90 of the sites. At 84 of the sites, this never happened, and at another 37 of the sites, it happened less than 1 percent of the time.

    In order for the difference between Q_{prev} and Q_{same} to exceed Q_{same}, Q_{prev} must exceed Q_{same}. This is caused by changes to the control that increase backwater, such as fill, macrophyte and algae growth, leaf accumulation, and deposition of logs and other woody debris. These changes are much more common at low flow than high flow; almost one-half of these were days when Q_{same} was less than the D90 (90 percent duration flow; 5,693 days of 12,794), and about 93 percent of them were days when Q_{same} was less than the D50 (50 percent duration flow; 11,913 days of 12,794). Beaver dams, swimmers' dams, or large logs on the control are among the likeliest types of obstructions that might cause backwater at medium or high flows. At low flow, small absolute changes to the control can result in large relative changes

to the rating, and the majority of the days when the difference between Q_{prev} and Q_{same} exceeded Q_{same} were during the time when medium to low flow is typical. Among all sites, 10,280 days of 12,794 were during July through December, and September was the month with the largest number of these days (2,084).

At 30 of the sites where the difference between Q_{prev} and Q_{same} exceeded Q_{same}, the difference between Q_{same} and Q_{prev} exceeded Q_{same} more than 2.5 percent of the time, or about 9 days per year. These 30 sites with the highest rates of large changes are predominantly either (1) small in area—the largest drainage area among them is 332 mi², (2) low in elevation—only 4 of them are at elevations greater than 1,000 ft, or (3) both. Seven of the sites drain more than 100 mi², and 6 of them are at elevations below 500 ft. Three of the 4 sites above 1,000 ft drain less than 20 mi². One site (01632000, North Fork Shenandoah River at Cootes Store) is neither low nor especially small; it is at an elevation of 1,051 ft and drains 210 mi². There, the difference between Q_{prev} and Q_{same} exceeded Q_{same} 2.8 percent of the time. This site was an outlier in several other stability metrics.

Of the 84 sites where the difference between Q_{prev} and Q_{same} never exceeded Q_{same}, most are on large streams or at high elevations. Forty-three sites are at elevations greater than 1,000 ft, and 29 drain more than 500 mi². Only 4 are at elevations less than 500 ft and drain less than 200 mi²; 1 of the 4 had only 2 years of record, which may or may not have been representative of long-term conditions.

8. Percentage of days when the difference between Q_{same} and Q_{prev} exceeded Q_{prev}

At 94 streamgages, the difference between Q_{same} and Q_{prev} exceeded Q_{prev} at least one time; at the other 80, this never happened (table 20). Patterns between this metric and metric 6 were generally similar. Sixty of the sites had non-zero values for both, whereas at 73 sites, the difference between Q_{same} and Q_{prev} never exceeded either Q_{same} or Q_{prev}.

In order for the difference between Q_{prev} and Q_{same} to exceed Q_{prev}, Q_{same} must exceed Q_{prev}. This is caused by scour and other changes to the control that increase flow relative to stage, such as removal of macrophytes and algae or the washing away of leaves, logs, and other woody debris. The changes to the control are likely to result from peaks or high flow pulses but are more likely to affect low flows than high flows. About one-fourth of the days with $Q_{prev} - Q_{same} > Q_{prev}$ came when Q_{same} was less than the D90 (3,241 days of 12,394), and about three-fourths of them came when Q_{same} exceeded the D50 (9,616 days of 12,394). Seasonality was less pronounced than it was for metric 7. Days when $Q_{prev} - Q_{same} > Q_{prev}$

were somewhat less frequent in spring than other seasons (2,938 days of 12,394 during March through June), but those days were generally fairly evenly distributed throughout the year.

Although the overall patterns were similar, this metric did not correlate as strongly with metric 7 as one might expect; rho was only 0.8772. This metric may be different because at some sites, scour is abrupt and fill is gradual, and at others, vice versa. Another possibility is that at some sites, algae and macrophyte growth or leaf accumulation are gradual, but dissipation is abrupt and often accompanied by scour. It is also possible that the two metrics are showing more or less the same thing. The correlation between them might be low despite the metrics showing the same thing because of the large number of near-zero observations from each metric that correspond with a zero observation for the other. Most likely, the two metrics are showing the same thing, but the metrics are affected principally by infrequent events and are therefore insensitive and imprecise.

Other Metrics

Seven additional metrics, 9–15, were considered.

9. Proportion of daily values that were estimated

This was one of the simplest metrics to compute and was determined from the series of daily values (Q_{meas}) itself; it was just the number of days per site with a remark code of "A:e" (table 13) divided by total days of record, computed for the period when AltFlows were available for each site (table 20). Total estimated daily values are most affected by issues with the stage record, including recurring problems with sedimentation related to the location of the stilling-well intake or bubbler orifice, isolated problems with equipment failure, and in winter, ice effect. At one site, the stream downcut at the control and left the stilling-well intakes out of the water for several days. Strictly speaking, this metric was not thought to be directly related to rating stability. This relation was investigated because sediment deposition is related to scour-and-fill shifting and to many problems with stilling-well intakes and bubble-gage orifices.

10. Proportion of daily values in winter that were estimated

The three months with the highest rates of estimated record were, in order, January, February, and December. Although intakes and orifices may be plugged during winter, and equipment failure is more common during winter than the rest of the year, the great majority of estimated days in winter are likely caused by ice effects. Ice effects may take the form of anchor ice accumulating on the control, a total freeze over of a stream, and less

commonly, ice jams. All of these can result in backwater in the gaging pool, which makes the stage-flow relation invalid until the ice melts or washes out. Since flow cannot be computed with the rating during these periods, it is estimated as mean daily flow. Like total estimated daily values, winter estimates should not, strictly speaking, be related to control and rating stability. This metric is presented in total by site in table 20.

11.   Average days that base ratings were in effect

The average number of days that base ratings were in effect at each site might seem to be a useful stability metric. However, it was almost completely uncorrelated with other metrics ($R^2 = 0.0069$ with percent zero difference and 0.0451 with total RMSE for AltFlows), highly affected by differences among field offices and individual hydrographer's preference, and affected by length of record at the streamgages. This metric is presented by site in table 20.

12. R^2 of most recent GAM_Q model

Many of the sites had multiple rating families, as described in previous sections of this report. Only the most recent rating family was included and is presented by site (table 20). GAM models were fit to gage height and flow from flow measurements; this was one of the three error terms from these models that was considered to be a candidate stability metric.

13. R^2 of most recent GAM_{GH} model

This is the second of three potential stability metrics derived from the analysis of variability of flow measurements; it was derived from GAM models that fit gage height as a smoothing function of flow. It was considered but rejected as a candidate stability metric. Its correlation with the other metrics was investigated. It is presented by site for the most recent rating family (table 20).

14.   Spearman's rho of the most recent rating family

This was the third of three potential stability metrics derived from analysis of variability of flow measurements subset by rating family. Unlike the other two, it had nothing to do with the GAM models, and as a rank-based statistic, it would be exactly the same regardless of which variable was considered to be dependent. It was considered but rejected as a candidate stability metric. Its correlation with the other metrics was investigated. It is presented, by site, for all rating families (table 13).

15.   Percentages of measurements with unexplained divergence from the rating

Described previously, the rate of unexplained divergence from the rating was lowest at some sites described as

having stable ratings and excellent stage record. It was considered but rejected as a candidate stability metric. Its correlation with the other metrics was investigated. It is presented by site, for the most recent rating family (table 20).

Relations Among Stability Metrics

Relations among stability metrics were investigated using three types of analysis. Spearman's rho correlation coefficients were determined among sites for all pairs of metrics and are presented in table 27, sorted by strength of correlation with stability class. Spearman's rho was chosen because the stability metrics had different frequency distributions and a rank-based statistic eliminated the need to transform them. The stability classes were assigned numeric values of 1, 2, 3, and 4, corresponding to Poor, Fair, Good, and Excellent, respectively, for purposes of computing the correlations. The correlations between stability class and the quantitative metrics were weak. No correlation had an absolute value greater than 0.5. The six metrics most strongly correlated with stability class were all derived from AltFlows; these were AltFlow absolute error divided by flow, difference $> Q_{same}$, RMSE, difference $> Q_{prev}$, percentage of average daily error, and percentage of zero difference of AltFlows. The R^2 of GAM_Q was next; no other metric had a rho with an absolute value greater than 0.3. These correlations are illustrated using a scatterplot matrix (plate 4).

Correlations among most of the error terms derived from AltFlows were generally the strongest of the entire set. As an example, the magnitude of Spearman's rho between AltFlow RMSE and 5 of the other 6 such terms ranged from 0.75 to 0.90.

The percentage of AltFlow daily error averaged was surprisingly strongly correlated with stability class (-0.4248) and some other metrics (|rho| > 0.6 for four other metrics), considering the problematic nature of its computation as discussed in its description (section "Metrics Derived from AltFlows"). Percentage of daily error averaged seems to be sensitive to relatively large differences in low flows, and if no other metrics sensitive to differences at low flow were available, it might be worth retaining despite problematic computation. However, AltFlow RMSE is only moderately affected by large-magnitude rating changes because it is computed and reported in log space. Percentage of zero-difference days is indifferent to flow magnitude, but the two metrics, based on differences exceeding magnitude of flow, are dominated by rating changes at low flow. In light of this, percentage of daily error averaged is probably too problematic a metric to consider as meaningful, although it is retained in this report for the purposes of documenting how it was considered.

Another candidate metric derived from AltFlows that is not clearly meaningful is the sum of error divided by the sum of flow. Its strongest correlation with any other proposed stability metric was -0.3248 with percentage of daily error

Table 27. Correlation matrix of Spearman's rho correlation coefficients for proposed rating-stability metrics developed from daily flows, shifted ratings, and flow measurements for streamgages in Virginia, water years 1991–2013.

[summary.numeric, Stability class, where 4 = excellent, 3 = good, 2 = fair, and 1 = poor.; RMSE, Root-mean-square error of AltFlows, in log units; diff.gt.Qsame, Proportion of days when $Q_{prev} - Q_{same} > Q_{same}$; abs.error.Q, For AltFlows, sum of absolute values of error divided by sum of flow; pct.error.avgd, Daily percent error, averaged; diff.gt.Qprev, Proportion of days when $Q_{prev} - Q_{same} > Q_{prev}$; gamQ.R2, R² of GAM models of flow as a function of gage height from flow measurements, for the most recent rating family; pct.zero.diff, Proportion of days of AltFlow record when $Q_{prev} = Q_{same}$; RatFam.rho, Spearman's rho for gage height and flow from flow measurements, for the most recent rating family; gamGH.R2, R² of GAM models of gage height as a function of flow from flow measurements, for the most recent rating family; pct.est, Percentage of daily values that were estimated; days.per.rat, Average time base ratings were in effect, in days; pct.est.winter, Percentage of daily values in winter that were estimated; pct.unexp.dev, Percentage of flow measurements that deviated from ratings by more than specified by Rantz and others, 1982; error.Q, For AltFlows, sum of error divided by sum of flow; >, greater than; AltFlow, alternative flow; GAM, generalized additive model; R², coefficient of determination; Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value]

Parameter	summary. numeric	abs. error.Q	diff.gt. Qsame	RMSE	diff.gt. Qprev	pct.error. avgd	pct.zero. diff	gamQ. R2	gamGH. R2	pct.est	RatFam. rho	days.per. rat	pct.est. winter	error.Q	pct.unexp. dev
summary. numeric	1.0000	-0.4969	-0.4762	-0.4732	-0.4381	-0.4248	0.3944	0.3790	0.2982	-0.2982	0.2686	0.1939	-0.1676	-0.1182	-0.0903
abs. error.Q	-0.4969	1.0000	0.7296	0.8523	0.7436	-0.6747	-0.8508	-0.6535	-0.5737	0.4827	-0.6106	-0.2265	0.3326	0.1903	0.1937
diff.gt. Qsame	-0.4762	0.7296	1.0000	0.8640	0.8772	-0.7969	-0.5846	-0.6224	-0.5074	0.4634	-0.4728	-0.2445	0.3151	0.1236	0.2748
RMSE	-0.4732	0.8523	0.8640	1.0000	0.8979	-0.7584	-0.7525	-0.6960	-0.5597	0.5200	-0.5589	-0.2553	0.3548	0.0911	0.2278
diff.gt. Qprev	-0.4381	0.7436	0.8772	0.8979	1.0000	-0.6754	-0.6226	-0.6589	-0.5335	0.4575	-0.5077	-0.2809	0.3182	0.0641	0.2491
pct.error. avgd	-0.4248	-0.6747	-0.7969	-0.7584	-0.6754	1.0000	0.5936	0.5760	0.4676	-0.4948	0.4264	0.1487	-0.3982	-0.3248	-0.2000
pct.zero. diff	0.3944	-0.8508	-0.5846	-0.7525	-0.6226	0.5936	1.0000	0.5760	0.4913	-0.4273	0.5510	0.0936	-0.3157	-0.0951	-0.1038
gamQ. R2	0.3790	-0.6535	-0.6224	-0.6960	-0.6589	0.5760	0.5760	1.0000	0.9020	-0.4077	0.7931	0.2131	-0.3577	-0.0430	-0.1437
gamGH. R2	0.2982	-0.5737	-0.5074	-0.5597	-0.5335	0.4676	0.4913	0.9020	1.0000	-0.3147	0.7518	0.1684	-0.2778	-0.0728	-0.1246
pct.est	-0.2982	0.4827	0.4634	0.5200	0.4575	-0.4948	-0.4273	-0.4077	-0.3147	1.0000	-0.3170	-0.1197	0.8584	0.0912	0.1347
RatFam. rho	0.2686	-0.6106	-0.4728	-0.5589	-0.5077	0.4264	0.5510	0.7931	0.7518	-0.3170	1.0000	0.2053	-0.2353	-0.0883	-0.1696
days.per. rat	0.1939	-0.2265	-0.2445	-0.2553	-0.2809	0.1487	0.0936	0.2131	0.1684	-0.1197	0.2053	1.0000	0.0116	0.1081	-0.1512
pct.est. winter	-0.1676	0.3326	0.3151	0.3548	0.3182	-0.3982	-0.3157	-0.3577	-0.2778	0.8584	-0.2353	0.0116	1.0000	0.0685	0.0515
error.Q	-0.1182	0.1903	0.1236	0.0911	0.0641	-0.3248	-0.0951	-0.0430	-0.0728	0.0912	-0.0883	0.1081	0.0685	1.0000	0.1334
pct.unexp. dev	-0.0903	0.1937	0.2748	0.2278	0.2491	-0.2000	-0.1038	-0.1437	-0.1246	0.1347	-0.1696	-0.1512	0.0515	0.1334	1.0000

averaged. The weakness of correlation between this metric and the others is likely due to positive and negative errors canceling each other out.

Two other proposed stability metrics that correlated only weakly with any other metric, including stability class, were percentage of flow measurements with unexplained deviation from the rating and length of time that base ratings were in effect. The length of time for base ratings to remain in effect would at first seem to be an obvious metric for rating stability, if not the most obvious imaginable. That it is at most weakly correlated with other stability metrics is a result of the role of hydrographer preference in achieving the same final expanded shifted rating tables through different combinations of ratings and shifts. The percentage of measurements with unexplained deviation from the rating is not such an obvious candidate for a stability metric. It emerged as a candidate metric during data exploration and seemed promising enough to include for this level of screening; it is apparently fairly arbitrary.

The two candidate metrics based on percentages of estimates were strongly correlated to each other (rho = 0.8584). This is reasonable because a disproportionate amount of estimated daily flow values comes in the winter. Both metrics were weakly correlated with stability class, -0.2982 for total estimates and -0.1676 for winter estimates. Total estimates were moderately correlated with R^2 of GAM_Q and several of the AltFlow-derived metrics, with the absolute value of rho as high as 0.5200 for RMSE and greater than 0.4 for six of the other metrics. Winter estimates had a weaker correlation with each of the other candidate metrics than did total estimates. Although these two candidate metrics are, as expected, weakly correlated with measures that are truly reflective of a streamgage's stage-flow relation, they still provide valuable information on the reliability of a streamgage in real time and are retained for further analysis.

The comparisons among rating-stability metrics included comparisons of error terms for different GAM models that were used to select the R^2 of GAM_Q as the preferred model for fitting flow and gage height from measurements. Of these error terms, the R^2 of GAM_Q is the most strongly correlated of the rating family metrics not only to stability class, but to all except two of the other proposed metrics. Those two were metrics that have already been rejected as not being meaningful are the percentage of unexplained deviation between measurements and ratings and the sum of AltFlow error divided by sum of flow. Considering the strength of its relations to other metrics, R^2 of GAM_Q was judged to be the strongest of the three rating family metrics under consideration.

Other stability metrics could have been developed from the set of data derived from measurements alone if the AltFlows had not been available. For instance, the residuals could have been sorted by time, and the number of them that exceeded or failed to exceed meaningful thresholds could have been counted either in total or in series. Change from measurement to measurement could also have been computed. Such metrics were not explored in this study, although they may have been meaningful, because AltFlows were available. Change from measurement to measurement and residuals would be considerably easier to compute because data acquisition and management would have been much simpler.

Another type of analysis of these candidate metrics is a series of boxplots for each metric, by stability class (fig. 8). Boxplots serve as a summary and check on the correlation analysis. They show strong separation between classes, defined as the 75th percentile exceeding the median from class to class and the median exceeding the 25th percentile from class to class, for only one candidate metric, sum of absolute error divided by sum of flow. Little or no separation between classes is visible for total estimates, winter estimates, AltFlow sum of error divided by sum of flow, base rating length, and percentage of unexplained deviation between measurements and ratings. Boxplots of the remaining metrics all show the expected patterns among classes but moderate or mixed separation among classes.

$Q_{prev} - Q_{same} > Q_{same}$ shows a stronger correlation with stability class than does $Q_{prev} - Q_{same} > Q_{prev}$, and the boxplots of the former show a greater separation by stability class than those of the latter. The two metrics are strongly, if not perfectly, correlated with each other (rho = 0.8772), and they are likely to be providing largely the same information in an imprecise way. Of the two metrics, $Q_{prev} - Q_{same} > Q_{same}$ was selected as the metric that provided a greater separation of values.

On the basis of this comparison, seven stability metrics were considered to be meaningful and were retained for comparison to site and basin characteristics. Total RMSE between log-transformed Q_{prev} and Q_{same} is affected by the magnitude and frequency of rating changes, and the transformation weights change throughout the range of flows so that none of high, medium, or low flows dominate the statistic. Days when $Q_{prev} - Q_{same} > Q_{same}$ is a measure of relatively large rating changes, most of which come at low flow. The sum of absolute AltFlow error divided by total flow is a flow-weighted statistic that is strongly affected by large-magnitude rating changes, which are predominantly at the high end of the rating; this metric is useful in evaluating rating stability relative to total volume of water during a period of time. The R^2 of GAM_Q is computed from flow measurements, not rating changes, and as such, was fast and easy to compute. Because most of the scatter on the GAM graphs is at the low end, R^2 of GAM_Q is most sensitive to variability at the low end of ratings. Unlike the various AltFlow metrics, R^2 of GAM_Q is independent of time, and unlike most of them, its magnitude is independent of the flow magnitude of the individual error. Percentage of days with zero difference between Q_{prev} and Q_{same} is a measure of the frequency of rating change. Percentage of total estimated days and percentage of estimated days in the winter are weakly related to control stability, if they are related to it at all, but provide information on the overall quality of the flow record and on the historical likelihood that winter record was affected by ice.
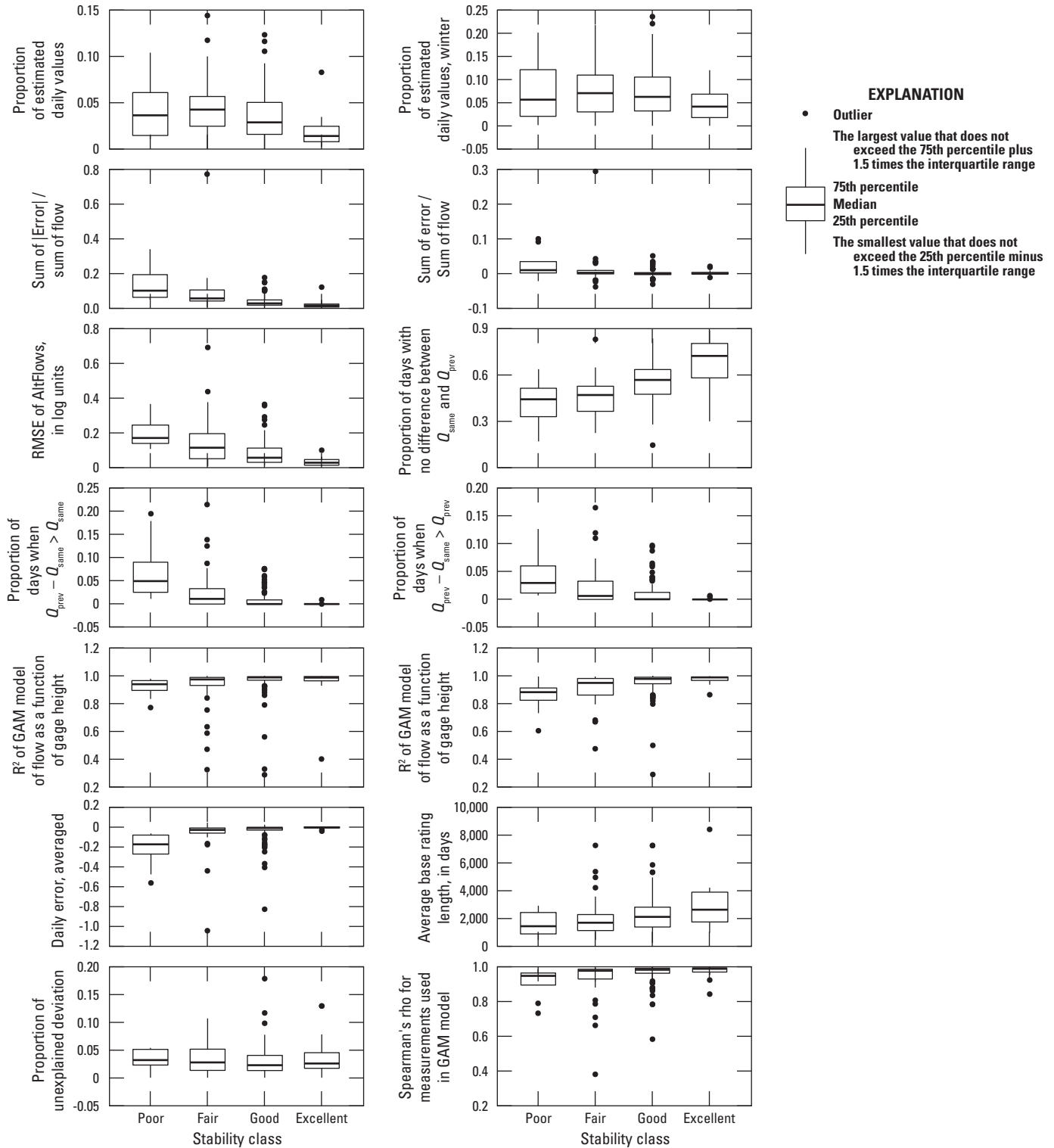
Figure 8.   Distribution of proposed stage-flow relation stability and real-time flow reliability metrics by descriptive stability class for streamgages in Virginia active on September 30, 2013. (GAM, generalized additive model; R2, coefficient of determination; Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value)

Stability Metrics and their Relations to Site and Basin Characteristics

Stepwise multiple regression analysis was done to determine whether relations among the various stability metrics and quantitative basin and site characteristics could be determined. These relations are weak, and the results of the regression models were not meaningful. The basin characteristics are those used in Virginia's most recent low-flow frequency report (Austin and others, 2011; https://pubs.usgs.gov/sir/2011/5143/tables/Table_09.xlsx). For four stability metrics (percentage of zero difference days, total site AltFlow RMSE, R^2 of the GAM models for the most recent rating family at each site, and days when $Q_{prev} - Q_{same} > Q_{same}$), regression models developed using stepwise regression had low multiple R^2 values, ranging from 0.3599 to 0.5542, even though the models included between 7 and 16 independent variables. Stepwise regression is controversial and is criticized when it is used to develop overfitted models that by coincidence have good error terms but prove not to be reproducible. In this case, however, the error terms were poor, indicating weak relations between stability metrics and basin characteristics, which is not a commonly criticized outcome for stepwise regression. Variables representing basin size, elevation, location (latitude and longitude), multiple physiography terms, and multiple impervious surface terms were identified as being weakly related to more than one stability term.

Review of scatterplot and correlation matrices also indicated few strong correlations between stability terms and basin characteristics (plate 5; table 28). The strongest correlation (Spearman's rho) between any stability metric and basin characteristic was -0.6655, between percentage of days when $Q_{same} - Q_{prev} > Q_{same}$ and longitude; in this case, large rating changes were common in eastern Virginia and rare or nonexistent in western Virginia. Weak correlations are to be expected with a dataset characterized by threshold effects and where many of the metrics under analysis include a high proportion of values that are similar. Highly local conditions, the configuration and composition of the streambed at a single cross section, are of the greatest importance to control and rating stability. Favorable local conditions may be found in isolation even in areas where stream conditions are generally unfavorable for streamgaging. Because only a single favorable cross section is needed for each streamgage, favorable conditions may be found or created in most streams where data are needed.

Relations between channel characteristics at high, medium, and low flows and stability metrics were explored. Cross-sectional area, stream depth, width, and velocity were determined for D1, D50, and D90 for the sites in the study from relations between these characteristics and flow in the flow measurement dataset. These values were then used to generate power curves against drainage area, and residuals for all these power curves were captured and included in exploratory analysis. Width-to-depth ratios were also determined for D1, D50, and D90. Scatterplot matrices were constructed, and Spearman's rho correlation coefficients were determined

among all the stability metrics and channel characteristics. The strongest relations were slightly stronger than those between stability metrics and basin characteristics but were still too weak to use for screening candidate streamgage locations or other actions. The maximum magnitudes of Spearman's rho in the matrix were about –0.72 between stream width at D90 and three metrics—RMSE, $Q_{same} - Q_{prev} > Q_{same}$, and $Q_{same} - Q_{prev} > Q_{prev}$. For all three, stability increased as width increased. As this was still a weak correlation, it was not pursued further during this study.

Caveats, Limitations, and Suggestions for Further Study

Several important sources of error in provisional flow data that are corrected in final flow data are missed by the process used to develop AltFlows. Most important and common are errors that are not caused by changes to the control and therefore are not corrected by changing ratings or shifts. These include ice-affected flows or missing records, which generally are estimated by hydrographic comparison to other streamgages. These errors might be corrected or at least adjusted, or daily flows might be estimated for the period that was in error.

Reliability of the stage record is equal in importance with rating stability in their effects on the reliability of a site's flow data in real time. The likelihood of plugged intakes or buried or exposed orifices is a function of the frequency of sediment deposition at a given point in a stream and, as such, is a characteristic of a given site. A streamgage may have a stable control but still be prone to recurring problems with the stage record that result in unreliable provisional data. The method developed to estimate Q_{prev} in this study does not account for problematic stage records.

Another difference between provisional and approved data not accounted for by the AltFlow procedure is that expanded shifted ratings were selected as snapshots at the times when flow was measured and the tens of thousands of other rating changes were ignored. Days when measurements were made have no particular relevance to the beginning or ending of shifts and rating changes. As discussed previously, about one-third (7,346 of 23,126) of shift entries began on days when flow was measured, and of these, 2,679 were apparently procedural entries for shifts that were implemented in multiple steps throughout the day. Forty-one percent of unique shifts (6,842 of 16,853) began on days of peaks, either floods or high-flow pulses, and another 7 percent (1,144 of 16,853) began the day after a peak. Many of the shifts that began on days when measurements were made began on days of peaks and high-flow pulses. Prorating certain types of shifts through time is routine; the AltFlow procedure does not account for these changed shifts. As a result, the AltFlow time series is unlikely to have much relation to provisional data as they initially appeared on the web, with the possible exception

Table 28. Correlation matrix of Spearman's rho correlation coefficients for selected rating stability metrics and selected basin characteristics for streamgages active in Virginia, September 30, 2013.

[avg.stability.score, Average of perceived stability class, where 4 = excellent, 3 = good, 2 = fair, and 1 = poor.; RMSE, Root-mean-square error of AltFlows, in log units; diff.gt.Qsame, Proportion of days when $Q_{prev} - Q_{same} > Q_{same}$; abs.error.Q, for AltFlows, sum of absolute values of error divided by sum of flow; pct.error.avgd, Daily percent error, averaged; diff.gt.Qprev, Proportion of days when $Q_{prev} - Q_{same} > Q_{prev}$; gamQR2, R^2 of GAM models of flow as a function of gage height from flow measurements, for the most recent rating family; pct.zero.diff, Proportion of days of AltFlow record when $Q_{prev} = Q_{same}$; pct. est, Percentage of daily values that were estimated; pct.est.winter, Percentage of daily values in winter that were estimated; >, greater than; GAM, generalized additive model; AltFlows, alternative flows; Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; Q_{same}, the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value]

Basin characteristic	avg.stability.score	abs.error.Q	diff.gt.Qsame	RMSE	diff.gt.Qprev	pct.error.avgd	pct.zero.diff	gamQ.R2	pct.est	pct.est.winter
DRNAREA	0.2732	-0.5721	-0.5117	-0.5312	-0.5606	0.4745	0.4573	0.5522	-0.4283	-0.4753
LOGDA	0.2732	-0.5721	-0.5117	-0.5312	-0.5606	0.4745	0.4573	0.5522	-0.4283	-0.4753
ELEV	0.4617	-0.5464	-0.6221	-0.5927	-0.5522	0.5414	0.5099	0.3917	-0.4742	-0.2771
BSLOPE	0.3818	-0.5313	-0.5112	-0.5139	-0.4586	0.4446	0.5041	0.3447	-0.4019	-0.2150
BASINPERIM	0.2843	-0.5967	-0.5321	-0.5650	-0.5848	0.4932	0.5029	0.5557	-0.4710	-0.5030
LAT_CENT	-0.0411	0.3544	0.4318	0.4756	0.4378	-0.3961	-0.3320	-0.4004	0.4648	0.5061
LONG_CENT	0.3857	-0.5477	-0.6655	-0.6514	-0.6111	0.5792	0.4758	0.4530	-0.5539	-0.4132
ELEV_PPT	0.3704	-0.3309	-0.4792	-0.4457	-0.4028	0.3861	0.3102	0.2147	-0.3735	-0.1630
PIEDMONT	-0.1195	0.0344	0.0451	0.0283	-0.0026	-0.0111	-0.0715	0.1309	0.0622	-0.1540
BLUERIDGE	0.0551	-0.1789	-0.2198	-0.1866	-0.1942	0.3202	0.1752	0.2323	-0.0821	-0.0768
V.R	0.4943	-0.4990	-0.5035	-0.5010	-0.4630	0.4164	0.4267	0.3007	-0.4307	-0.3273
APP_PLAT	-0.0200	-0.1941	-0.1496	-0.1693	-0.1549	0.1379	0.1384	0.0127	-0.2308	-0.2121
MESOZOIC	0.0313	-0.0271	-0.0106	-0.0150	-0.0547	0.1111	0.0204	0.1885	0.0782	0.0087
WINTER_PRECIP	-0.0527	-0.2824	-0.2924	-0.3764	-0.3083	0.3059	0.3208	0.3128	-0.3284	-0.3943
INTENS_2Y24	-0.2347	0.0649	0.0315	0.0501	0.0376	0.0754	0.0082	0.0899	0.1524	0.0157
IMPERV_0	0.0230	-0.0399	0.0657	0.0161	0.0545	-0.1838	0.0361	0.0515	0.0277	0.0009
IMPERV_1.5	0.0442	0.0081	-0.0669	-0.0635	-0.0618	0.1808	0.0356	0.0097	0.0713	0.1480
IMPERV_6.10	-0.0979	0.1072	0.0176	0.0727	0.0125	0.1114	-0.1217	-0.1011	0.0127	-0.0072
IMPERV_26.50	-0.0773	0.0341	-0.0227	0.0222	-0.0186	0.1342	-0.0499	-0.0889	-0.1318	-0.1651

of the end of the study period. AltFlows do, however, provide information on changes in the shifted rating from site visit to site visit, and it provides information on how that shifted rating changed throughout the range of observed flows.

All of the stability metrics that were developed and proposed through the course of this study are difficult to verify externally because there is no previous, widely accepted external definition of rating stability. To the extent that descriptive stability classes are valid, they serve as an external check on the other metrics. Since the metrics all compared imprecisely to the descriptive stability classes, which themselves were imprecise, they all are imprecise measurements of rating stability or flow record reliability. Other than that comparison, the metrics were selected in terms of correlation to each other, and those correlations were generally fairly weak. These stability metrics are probably appropriate to use to separate streamgages into general classes of Excellent, Good, Fair, and Poor, but small differences in a metric are unlikely to mean very much.

Descriptions from hydrographer interviews were essential for interpreting quantitative analyses. The survey in which hydrographers were asked to grade control stability on a numeric scale was weakened by differences in individual impressions about stability. The stability scores provided by the individual hydrographer who was familiar with the most streamgages were correlated more strongly with quantitative metrics than were the averaged scores. Inconsistent impressions about stability are unlikely to make a substantial difference in flow data computation but greatly complicate creating and interpreting a survey of hydrographers about controls conditions. The survey process might have been stronger had it been done as a round-table discussion among senior hydrographers and differences in perspective about sites that were rated differently by different people had been resolved.

Future studies might consider attempting to separate individual ratings into parts representing section control, channel control, and overbank flow, and treating them separately. During the course of this study, exploratory analysis was done using dominant particle-size information captured during flow measurements. The analysis was less conclusive than seemed plausible. Quantitative measures of section control particle size might allow more conclusive analysis.

Summary

The U.S. Geological Survey, in cooperation with the Virginia Department of Environmental Quality, has quantified several measures of rating stability and the frequency and magnitude of changes to ratings through time for 174 real-time continuous streamgages active in Virginia as of September 30, 2013. The purpose of this report is to quantify the stability of stage-flow ratings in Virginia to help evaluate their reliability in providing real-time flow data. Relations between stage and flow from all flow measurements available at each site were determined. Mean daily flows for water years 1991–2013

were compared to flows that would have been computed from the rating in effect when the previous flow measurement was made.

Flow data computation procedures have changed substantially during water years 1991-2013. Timing of record computation is among the most critical of these changes. From 1991 through 2001, the median number of days between the start date of the shift, the first date of data for which it was intended to modify, and the date it was created in the office by a hydrographer, fluctuated between about 240 and about 300 days. The 75th percentile of days between start date and creation date of shifts was more than 365 for every year during that period. Beginning in 2002, in recognition of the growing importance to data users of near-real-time flow on the internet, a greater effort began to work records continuously. The median period between the start date of a shift and its final modification decreased by about 4 months from 2001 to 2002. Only in 2012 and 2013 did one-half of the shifts have a delay between start date and final modification of about 60 days, which is close to the 8-week interval between routine streamgage visits.

Curves were fit through all available flow measurements for all the gages in Virginia's real-time network as of September 30, 2013, that had at least 20 flow measurements with positive flow values. Generalized additive models (GAMs) were found to fit measurements better than LOESS curves. The GAM curves served as an average long-term rating. For each measurement with a positive flow value, residuals from the GAM curve were calculated. The residuals were plotted as a time series and by Julian date. The time-series plots were used to identify major changes to the control, and the measurements in the periods of equilibrium between major changes were assigned to rating families. At the 174 sites, 301 rating families were identified. At 107 of the sites, all measurements fit a single rating family. An additional 127 rating families were identified at the 67 sites where there were 2 or more rating families. Documented explanations were found for 67 of those 127 rating families. The most common reasons for the control to change enough to represent a new rating family are moving the gage (28 times), floods (26 times), and construction activities including bridge construction and removal, weir and control construction and removal, and channel or bed modifications (13 times). Provisional flow data from any streamgage that has recently experienced a major flood, regardless of historical stability, is more uncertain than usual until post-flood evidence emerges that the rating has remained stable or, if changed, is again well defined.

A direct comparison between provisional flow data originally displayed on the web in near-real time and flow data approved for publication following subsequent flow measurements and review could not be made because provisional flow data have not been archived. As a substitute, alternative flow (AltFlow) tables were constructed for periods with complete records of shifts and ratings. Daily flows were acquired for these periods. Expanded shifted ratings were acquired for days during these periods when flow measurements were made.

Gage heights corresponding to mean daily flows were back-calculated and identified as belonging to measurement-to-measurement periods. These gage heights were then related to two sets of ratings, those in effect when the measurement-to-measurement period began (Q_{same}) and those in effect when the previous measurement-to-measurement period began (Q_{prev}). Q_{same} was used instead of the actual published daily values to avoid rounding errors. Data availability varied by site, even for sites with complete flow record throughout water years 1991–2013 because of differences among field offices in data archiving. Many sites with complete records of daily values for water years 1991–2013 had AltFlow records that began in 2002.

Several metrics that summarized AltFlow tables were computed and evaluated with particular importance being given to how well they agreed with descriptive stability classes developed from hydrographer interviews. Of these stability metrics, four were determined to be meaningful and to represent different aspects of control stability that might be relevant to water managers. Total root mean square error (RMSE) between log-transformed Q_{prev} and Q_{same} is affected by the magnitude and frequency of rating changes and the transformation weight changes throughout the range of flows so that high, medium, or low flows do not dominate the statistic. The number of days when the difference between Q_{prev} and Q_{same} is freater than Q_{same} is a measure of relatively large rating changes, most of which come at low flow. The sum of absolute AltFlow error divided by total flow is a flow-weighted statistic that is strongly affected by large-magnitude rating changes, which are predominantly at the high end of the rating, and it is useful in evaluating rating stability relative to total volume of water in a period. Percentage of days with zero difference between Q_{prev} and Q_{same} is a measure of the frequency of rating change.

Three other meaningful metrics of control stability or provisional flow-data quality were computed. The coefficient of determination (R^2) of GAM_Q is computed from flow measurements, not rating changes. Because most of the scatter on the GAM models is at the low end of the plot, R^2 of GAM_Q is most sensitive to variability at the low end of ratings. Unlike the various AltFlow metrics, it is independent of time, and unlike most of them, its magnitude is independent of the flow magnitude of the individual error. Percentage of total estimated days and percentage of estimated days in the winter are weakly related to control stability, if they are related to it at all, but provide information on the overall quality of the flow record and on the likelihood that historical winter record was affected by ice.

Correlations among metrics varied, indicating they responded to different aspects of control stability. Correlations among most of the error terms derived from AltFlows were generally the strongest of the entire set. As an example, the magnitude of Spearman's rho between AltFlow RMSE and 5 of the other 6 such terms ranged from 0.75 to 0.90. The R^2 of GAM_Q was correlated with the four meaningful AltFlow stability metrics (Spearman's rho absolute values ranging from 0.5760 to 0.6960).

The two candidate metrics that are based on percentages of estimates were strongly correlated to each other (rho = 0.8584). Both these metrics were weakly correlated with stability class, –0.2982 for total estimates and –0.1676 for winter estimates. Total estimates were moderately correlated with R^2 of GAM_Q and several of the AltFlow-derived metrics; the absolute value of rho was as high as 0.5200 with RMSE and greater than 0.4 for six of the other metrics.

Stepwise multiple regression analysis was done to determine whether relations among the various stability metrics and quantitative basin and site characteristics could be determined. These relations were weak, and the regression models were not meaningful. Review of scatterplot and correlation matrices also indicated few strong correlations between stability terms and basin characteristics. Although quantitative relations between stability metrics and basin and site characteristics were all weak, some common patterns emerged. Streamgages on large streams (>500-square mile drainage area) and at high elevations (>1,000 feet) were more likely to have stable controls and ratings than streamgages on small streams (<100-square mile drainage area) and at low elevations (<500 feet). Streamgages in western Virginia were more likely to have stable controls than were streamgages in northeastern Virginia, particularly small streams. There were exceptions to all three generalizations, and streamgages that were intermediate in those characteristics varied widely in stability.

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Table 2.   Earliest dates for base ratings and shifts in the Virginia node of the National Water Information System database for streamgages active as of September 30, 2013.

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	
		Base rating	Shift
01613900	Hogue Creek near Hayfield, VA	3/17/1999	9/20/2001
01615000	Opequon Creek near Berryville, VA	2/15/1984	11/30/1984
01616100	Dry Marsh Run near Berryville, VA	8/19/2002	8/20/2002
01620500	North River near Stokesville, VA	1/13/1998	8/21/2001
01621050	Muddy Creek at Mount Clinton, VA	9/30/1995	12/1/1996
01622000	North River near Burketown, VA	9/30/1997	8/3/2001
01625000	Middle River near Grottoes, VA	12/17/1982	9/30/1986
01626000	South River near Waynesboro, VA	3/19/1983	9/30/1986
01626850	South River near Dooms, VA	12/16/1982	4/17/1987
01627500	South River at Harriston, VA	1/8/1998	11/26/2000
01628500	South Fork Shenandoah River near Lynnwood, VA	12/17/1982	8/19/1985
01629500	South Fork Shenandoah River near Luray, VA	9/30/1999	8/2/2001
01631000	South Fork Shenandoah River at Front Royal, VA	11/5/1985	8/17/2001
01632000	North Fork Shenandoah River at Cootes Store, VA	9/6/1996	3/3/1997
01632082	Linville Creek at Broadway, VA	8/8/1985	8/23/1985
01632900	Smith Creek near New Market, VA	9/30/1983	8/21/1985
01633000	North Fork Shenandoah River at Mount Jackson, VA	3/18/1999	1/31/2001
01634000	North Fork Shenandoah River near Strasburg, VA	9/30/1984	9/30/1996
01634500	Cedar Creek near Winchester, VA	2/15/1984	9/27/1985
01635500	Passage Creek near Buckton, VA	2/26/1979	4/17/1987
01636316	Spout Run at Rt 621 near Millwood, VA	8/22/2002	9/5/2002
01636690	Piney Run near Lovettsville, VA	7/31/2001	9/27/2001
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	6/27/2001	7/4/2001
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	7/19/2001	7/19/2001
01638480	Catoctin Creek at Taylorstown, VA	11/7/1997	9/24/2001
01643590	Limestone Branch near Leesburg, VA	8/22/2001	8/22/2001
01643700	Goose Creek near Middleburg, VA	3/23/1991	6/15/2001
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	7/18/2001	8/11/2001
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	7/17/2001	7/17/2001
01644000	Goose Creek near Leesburg, VA	3/21/1998	11/28/2000
01644280	Broad Run near Leesburg, VA	9/1/2001	1/7/2002
01645704	Difficult Run above Fox Lake near Fairfax, VA	9/20/2007	9/20/2007
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	9/19/2007	9/19/2007
01646000	Difficult Run near Great Falls, VA	10/23/1983	9/10/1985
01646305	Dead Run at Whann Avenue near Mclean, VA	1/9/2008	1/9/2008
01652500	Fourmile Run at Alexandria, VA	9/30/1985	9/30/1998
01653000	Cameron Run at Alexandria, VA	9/30/1994	9/30/1996
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	10/18/2011	10/29/2011
01654000	Accotink Creek near Annandale, VA	10/25/1997	9/30/2001
01656000	Cedar Run near Catlett, VA	5/4/1984	9/27/1985
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	9/20/2007	9/20/2007
01658500	South Fork Quantico Creek near Independent Hill, VA	9/30/1995	10/19/1996
01660400	Aquia Creek near Garrisonville, VA	1/19/1996	11/3/1999
01662800	Battle Run near Laurel Mills, VA	2/15/1984	10/20/1984
01663500	Hazel River at Rixeyville, VA	9/12/2001	10/19/2001

Table 2. Earliest dates for base ratings and shifts in the Virginia node of the National Water Information System database for streamgages active as of September 30, 2013.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	
		Base rating	Shift
01664000	Rappahannock River at Remington, VA	1/9/1998	9/30/2001
01665500	Rapidan River near Ruckersville, VA	6/27/1995	9/30/1998
01666500	Robinson River near Locust Dale, VA	9/30/1982	9/30/1984
01667500	Rapidan River near Culpeper, VA	3/15/1999	1/26/2001
01668000	Rappahannock River near Fredericksburg, VA	9/30/1980	9/8/1999
01669000	Piscataway Creek near Tappahannock, VA	5/2/2001	9/18/2001
01669520	Dragon Swamp at Mascot, VA	2/4/1998	3/24/2001
01670400	North Anna River near Partlow, VA	9/30/1982	9/30/1984
01671020	North Anna River at Hart Corner near Doswell, VA	3/8/1989	7/29/1998
01671025	North Anna River above Little River near Doswell, VA	6/29/2004	6/29/2004
01671100	Little River near Doswell, VA	2/5/1998	6/8/2001
01672500	South Anna River near Ashland, VA	10/14/1982	11/25/1996
01673000	Pamunkey River near Hanover, VA	11/28/1993	1/28/1997
01673550	Totopotomoy Creek near Studley, VA	3/26/1984	9/28/1985
01673800	Po River near Spotsylvania, VA	3/30/1984	8/21/1985
01674000	Mattaponi River near Bowling Green, VA	10/25/1982	10/16/1984
01674500	Mattaponi River near Beulahville, VA	8/29/1989	8/24/1995
02011400	Jackson River near Bacova, VA	9/30/1991	9/30/1994
02011460	Back Creek near Sunrise, VA	1/8/1998	6/5/2001
02011470	Back Creek at Sunrise, VA	10/23/1984	9/30/1994
02011490	Little Back Creek near Sunrise, VA	9/30/1984	9/30/2002
02011500	Back Creek near Mountain Grove, VA	9/30/1993	9/30/1994
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	1/29/1994	9/30/1994
02013000	Dunlap Creek near Covington, VA	1/20/1988	6/30/1995
02013100	Jackson River below Dunlap Creek at Covington, VA	9/30/1981	6/27/1995
02014000	Potts Creek near Covington, VA	12/5/1993	1/15/1995
02015700	Bullpasture River at Williamsville, VA	1/19/1996	7/21/1998
02016000	Cowpasture River near Clifton Forge, VA	9/30/1992	11/4/1999
02016500	James River at Lick Run, VA	9/30/1992	3/21/1998
02017500	Johns Creek at New Castle, VA	12/5/1993	9/24/2001
02018000	Craig Creek at Parr, VA	12/6/1993	9/30/2001
02018500	Catawba Creek near Catawba, VA	2/17/1998	9/24/2001
02019500	James River at Buchanan, VA	9/30/1995	4/20/1998
02020500	Calfpasture River above Mill Creek at Goshen, VA	9/30/1998	10/15/1998
02021500	Maury River at Rockbridge Baths, VA	9/30/1984	12/2/1996
02022500	Kerrs Creek near Lexington, VA	3/21/2000	3/21/2001
02024000	Maury River near Buena Vista, VA	9/30/1992	9/30/1999
02024752	James River at Blue Ridge Pkwy near Big Island, VA	6/7/2005	9/1/2006
02024915	Pedlar River at Forest Road near Buena Vista, VA	11/5/2002	11/7/2002
02025500	James River at Holcomb Rock, VA	9/30/1990	10/9/1998
02026000	James River at Bent Creek, VA	9/30/1981	7/31/2001
02027000	Tye River near Lovingston, VA	1/8/1998	10/8/1998
02027500	Piney River at Piney River, VA	4/29/1999	3/21/2001
02028500	Rockfish River near Greenfield, VA	12/5/1993	7/16/1998
02029000	James River at Scottsville, VA	9/30/1979	11/10/1996

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Table 2. Earliest dates for base ratings and shifts in the Virginia node of the National Water Information System database for streamgages active as of September 30, 2013.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	
		Base rating	Shift
02030000	Hardware River below Briery Run near Scottsville, VA	9/30/1989	9/10/1997
02030500	Slate River near Arvonia, VA	9/30/1980	10/29/1984
02031000	Mechums River near White Hall, VA	2/23/1994	9/17/2001
02032250	Moormans River near Free Union, VA	11/3/1985	7/6/2005
02032640	North Fork Rivanna River near Earlysville, VA	9/30/1993	9/30/1993
02034000	Rivanna River at Palmyra, VA	1/24/1999	3/30/2001
02035000	James River at Cartersville, VA	11/6/1985	7/29/1986
02036500	Fine Creek at Fine Creek Mills, VA	11/26/1983	10/2/1984
02037000	James River And Kanawha Canal near Richmond, VA	9/30/1993	3/29/2001
02037500	James River near Richmond, VA	10/9/1996	9/30/1997
02038850	Holiday Creek near Andersonville, VA	9/30/1999	6/5/2001
02039000	Buffalo Creek near Hampden Sydney, VA	12/17/1982	9/30/1984
02039500	Appomattox River at Farmville, VA	9/30/1987	3/22/2001
02040000	Appomattox River at Mattoax, VA	11/7/1985	11/6/1985
02040892	Appomattox River at Route 602 near Mannboro, VA	6/21/2011	6/21/2011
02041000	Deep Creek near Mannboro, VA	11/27/1983	10/2/1984
02041650	Appomattox River at Matoaca, VA	12/3/1993	6/17/2000
02042500	Chickahominy River near Providence Forge, VA	9/30/1993	12/9/1996
02044500	Nottoway River near Rawlings, VA	4/18/2000	6/5/2001
02045500	Nottoway River near Stony Creek, VA	9/30/1984	10/2/1984
02046000	Stony Creek near Dinwiddie, VA	3/22/2001	9/26/2001
02047000	Nottoway River near Sebrell, VA	2/9/1998	9/30/2000
02047500	Blackwater River near Dendron, VA	2/21/1982	10/1/1984
02049500	Blackwater River near Franklin, VA	10/6/1981	5/3/1997
02051000	North Meherrin River near Lunenburg, VA	2/4/1998	2/4/1998
02051500	Meherrin River near Lawrenceville, VA	9/30/1980	10/2/1996
02052000	Meherrin River at Emporia, VA	1/16/1998	6/8/2001
02053800	South Fork Roanoke River near Shawsville, VA	4/11/1983	9/30/1984
02054500	Roanoke River at Lafayette, VA	4/18/2000	1/20/2001
02054530	Roanoke River at Glenvar, VA	12/11/1991	1/4/1992
02055000	Roanoke River at Roanoke, VA	3/29/1994	8/20/2000
02055100	Tinker Creek near Daleville, VA	9/30/1993	9/30/1996
02056000	Roanoke River at Niagara, VA	9/30/1992	1/24/2001
02056650	Back Creek near Dundee, VA	9/30/1999	9/30/2001
02056900	Blackwater River near Rocky Mount, VA	1/15/1995	3/30/2001
02058400	Pigg River near Sandy Level, VA	9/7/1987	9/8/1997
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	9/29/2006	9/15/2007
02059500	Goose Creek near Huddleston, VA	9/30/1995	10/14/2001
02060500	Roanoke River at Altavista, VA	11/5/1985	9/26/1988
02061000	Big Otter River near Bedford, VA	12/10/2006	8/5/2007
02061500	Big Otter River near Evington, VA	12/5/1993	6/6/2001
02062500	Roanoke (Staunton) River at Brookneal, VA	9/30/1992	10/3/1995
02064000	Falling River near Naruna, VA	2/15/1984	5/25/1985
02065500	Cub Creek at Phenix, VA	11/28/1993	10/8/1998
02066000	Roanoke (Staunton) River at Randolph, VA	8/18/1985	6/24/1995

Table 2. Earliest dates for base ratings and shifts in the Virginia node of the National Water Information System database for streamgages active as of September 30, 2013.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	
		Base rating	Shift
02069700	South Mayo River near Nettleridge, VA	3/20/2000	3/20/2001
02070000	North Mayo River near Spencer, VA	12/5/1993	9/25/2001
02071530	Smith River at Smith Riv Church near Woolwine, VA	10/20/1994	7/29/1997
02072000	Smith River near Philpott, VA	6/10/1981	10/7/1997
02072500	Smith River at Bassett, VA	9/30/1985	9/30/1995
02073000	Smith River at Martinsville, VA	3/28/1994	12/6/2001
02074500	Sandy River near Danville, VA	1/5/1982	6/29/1985
02075045	Dan River at Stp near Danville, VA	9/30/1993	10/7/1996
02075500	Dan River at Paces, VA	11/2/1981	10/3/1995
02077000	Banister River at Halifax, VA	10/18/1981	1/4/1985
02077500	Hyco River near Denniston, VA	9/30/1984	10/5/1996
02079640	Allen Creek near Boydton, VA	3/7/1984	5/25/1985
03164000	New River near Galax, VA	9/30/1991	8/25/1994
03165000	Chestnut Creek at Galax, VA	9/30/1985	9/30/1996
03165500	New River at Ivanhoe, VA	12/2/1996	9/30/1997
03167000	Reed Creek at Grahams Forge, VA	6/5/1992	1/20/2001
03168000	New River at Allisonia, VA	11/24/1992	9/30/1994
03170000	Little River at Graysontown, VA	9/30/1991	9/30/2000
03171000	New River at Radford, VA	9/30/1989	9/30/1994
03173000	Walker Creek at Bane, VA	3/25/1993	9/30/1994
03175500	Wolf Creek near Narrows, VA	11/5/1985	9/30/1994
03176500	New River at Glen Lyn, VA	3/25/1993	9/30/1994
03177710	Bluestone River at Falls Mills, VA	3/24/1993	8/25/1993
03207800	Levisa Fork at Big Rock, VA	1/25/1984	9/30/1994
03208500	Russell Fork at Haysi, VA	2/1/1985	9/30/1994
03208950	Cranes Nest River near Clintwood, VA	4/4/1977	9/30/1988
03209000	Pound River below Flannagan Dam, near Haysi, VA	12/2/1985	9/30/1994
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	12/24/1992	9/30/1996
03473000	South Fork Holston River near Damascus, VA	2/11/1994	9/30/1996
03474000	Middle Fork Holston River at Seven Mile Ford, VA	10/9/1976	9/30/1996
03475000	Middle Fork Holston River near Meadowview, VA	1/4/1992	9/30/1996
03478400	Beaver Creek at Bristol, VA	9/30/1991	9/30/1996
03488000	North Fork Holston River near Saltville, VA	1/13/1989	9/30/1996
03490000	North Fork Holston River near Gate City, VA	3/31/2012	12/27/2012
03524000	Clinch River at Cleveland, VA	12/24/1992	10/2/1995
03524500	Guest River at Coeburn, VA	8/1/2012	4/20/2013
03527000	Clinch River at Speers Ferry, VA	9/30/2001	10/3/2001
03529500	Powell River at Big Stone Gap, VA	9/30/2001	10/3/2001
03531500	Powell River near Jonesville, VA	9/30/1994	9/30/1995

Table 3   53

Table 3. Number of unique shifts recorded in the National Water Information System at streamgages in Virginia active as of September 30, 2013; includes multiple shifts begun on the same day.

[--, no shifts because data are unavailable for the period; VA, Virginia; Rt, Route]

Number of unique shifts

Streamgage number	Streamgage name	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
01613900	Hogue Creek near Hayfield, VA	--	--	--	--	--	--	--	--	--	--	--	14	16	9	20	6	3	10	6	24	5	2	18	14	147
01615000	Opequon Creek near Berryville, VA	5	14	21	5	12	13	8	19	--	--	--	--	--	1	6	6	3	8	12	5	16	17	16	11	198
01616100	Dry Marsh Run near Berryville, VA	--	--	--	--	--	--	--	--	--	--	--	--	3	6	5	7	10	6	10	12	10	12	9	11	101
01620500	North River near Stokesville, VA	--	--	--	--	--	--	--	--	--	--	--	4	2	6	5	12	5	7	10	9	7	16	18	16	117
01621050	Muddy Creek at Mount Clinton, VA	--	--	--	--	--	--	2	11	9	8	15	15	18	6	6	5	8	9	9	14	10	11	10	13	179
01622000	North River near Burketown, VA	--	--	--	--	--	--	--	--	--	--	--	5	13	4	6	3	2	12	8	6	5	1	9	8	82
01625000	Middle River near Grottoes, VA	6	10	7	9	7	10	7	7	10	10	9	11	13	6	8	3	4	4	10	3	2	2	9	5	172
01626000	South River near Waynesboro, VA	7	6	9	8	12	3	9	5	13	24	17	11	10	4	5	3	2	13	9	7	2	1	14	7	201
01626850	South River near Dooms, VA	4	6	4	5	0	4	4	1	--	--	--	--	--	--	--	3	4	13	29	10	5	2	21	11	126
01627500	South River at Harriston, VA	--	--	--	--	--	--	--	--	--	--	1	15	14	6	12	5	1	9	13	5	3	3	9	12	108
01628500	South Fork Shenandoah River near Lynnwood, VA	4	9	8	10	5	15	9	7	12	18	10	11	13	3	16	7	6	7	8	3	5	1	9	7	203
01629500	South Fork Shenandoah River near Luray, VA	--	--	--	--	--	--	--	--	--	--	--	4	13	8	12	7	0	6	9	3	9	0	11	5	86
01631000	South Fork Shenandoah River at Front Royal, VA	--	--	--	--	--	--	--	--	--	--	--	5	10	5	4	7	5	6	9	9	13	7	15	12	107
01632000	North Fork Shenandoah River at Cootes Store, VA	--	--	--	--	--	--	--	2	3	1	6	6	4	7	11	14	6	11	8	12	11	8	7	7	124
01632082	Linville Creek at Broadway, VA	8	14	14	12	18	24	11	13	5	9	11	22	7	14	6	2	6	9	11	7	5	5	10	9	252
01632900	Smith Creek near New Market, VA	2	8	10	13	5	16	13	12	12	13	13	7	27	16	6	7	16	8	12	11	26	13	16	11	293
01633000	North Fork Shenandoah River at Mount Jackson, VA	--	--	--	--	--	--	--	--	--	--	--	18	16	6	4	6	3	3	9	9	2	3	11	10	100
01634000	North Fork Shenandoah River near Strasburg, VA	--	--	--	--	--	--	1	4	9	10	9	9	7	0	9	6	6	5	12	9	13	12	14	8	143
01634500	Cedar Creek near Winchester, VA	8	33	9	19	17	20	10	13	19	11	19	6	6	6	6	10	4	6	13	6	12	2	11	8	274
01635500	Passage Creek near Buckton, VA	3	14	8	9	2	4	8	6	8	8	12	4	6	12	8	3	3	6	4	2	1	2	10	6	149
01636316	Spout Run at Rt 621 near Millwood, VA	--	--	--	--	--	--	--	--	--	--	--	--	3	4	9	9	6	5	12	11	11	9	7	10	96
01636690	Piney Run near Lovettsville, VA	--	--	--	--	--	--	--	--	--	--	--	4	7	8	5	9	3	8	6	13	9	14	19	13	118
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	--	--	--	--	--	--	--	--	--	--	--	4	4	11	3	6	9	2	14	16	12	14	14	6	115
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	--	--	--	--	--	--	--	--	--	--	--	12	6	7	3	6	4	7	12	15	13	11	12	18	126
01638480	Catoctin Creek at Taylorstown, VA	--	--	--	--	--	--	--	--	--	--	--	4	11	7	10	10	10	21	19	3	1	3	11	10	120
01643590	Limestone Branch near Leesburg, VA	--	--	--	--	--	--	--	--	--	--	--	1	4	8	3	6	8	9	11	13	9	12	18	31	133
01643700	Goose Creek near Middleburg, VA	--	--	--	--	--	--	--	--	--	--	--	6	5	3	2	10	8	3	14	13	10	17	13	11	115
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	--	--	--	--	--	--	--	--	--	--	--	4	14	10	7	7	5	5	10	14	21	14	15	13	138
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	--	--	--	--	--	--	--	--	--	--	--	6	5	13	7	5	5	7	17	13	15	13	23	14	143
01644000	Goose Creek near Leesburg, VA	--	--	--	--	--	--	--	--	--	--	--	33	24	5	8	6	17	31	14	13	3	8	13	6	179
01644280	Broad Run near Leesburg, VA	--	--	--	--	--	--	--	--	--	--	--	--	5	0	3	4	6	7	11	12	9	14	14	7	92
01645704	Difficult Run above Fox Lake near Fairfax, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	13	10	6	12	8	11	63
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	15	13	17	17	30	14	113
01646000	Difficult Run near Great Falls, VA	12	8	10	19	14	22	3	15	30	12	12	18	4	6	4	9	1	13	2	3	3	6	10	10	246
01646305	Dead Run at Whann Avenue near Mclean, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11	17	21	18	55	33	155
01652500	Fourmile Run at Alexandria, VA	--	--	--	--	--	--	--	--	--	--	--	17	8	10	7	9	10	8	9	16	13	10	18	14	182
01653000	Cameron Run at Alexandria, VA	--	--	--	--	--	--	--	--	--	--	--	15	9	16	8	8	11	2	7	11	6	14	18	9	167
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	37	20	61
01654000	Accotink Creek near Annandale, VA	--	--	--	--	--	--	--	--	--	--	--	8	32	8	6	11	3	7	18	8	17	8	19	7	152
01656000	Cedar Run near Catlett, VA	5	15	11	21	17	15	12	21	27	20	9	12	8	10	4	3	2	15	7	8	7	4	10	7	270

Table 3. Number of unique shifts recorded in the National Water Information System at streamgages in Virginia active as of September 30, 2013; includes multiple shifts begun on the same day.—Continued

[--, no shifts because data are unavailable for the period; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	9	10	14	10	15	31	18	107
01658500	South Fork Quantico Creek near Independent Hill, VA	--	--	--	--	--	--	6	23	8	15	17	21	10	10	28	8	11	19	6	13	15	22	50	20	302
01660400	Aqua Creek near Garrisonville, VA	--	--	--	--	--	--	--	--	--	3	11	17	7	9	10	6	13	8	7	9	14	18	9	12	153
01662800	Battle Run near Laurel Mills, VA	6	27	14	28	16	25	-	2	13	5	9	11	11	10	12	5	6	15	5	12	4	4	11	8	259
01663500	Hazel River at Rixeyville, VA	--	--	--	--	--	--	--	--	--	--	--	8	11	2	1	8	3	11	14	8	9	6	14	6	101
01664000	Rappahannock River at Remington, VA	--	--	--	--	--	--	--	--	--	--	5	4	7	3	0	3	3	20	12	5	11	13	16	8	105
01665500	Rapidan River near Ruckersville, VA	--	--	--	--	--	--	3	--	3	6	5	9	8	12	12	14	0	20	9	7	4	4	15	10	138
01666500	Robinson River near Locust Dale, VA	9	11	14	14	3	17	11	7	18	12	6	10	6	14	6	19	8	9	12	7	9	6	15	15	258
01667500	Rapidan River near Culpeper, VA	--	--	--	--	--	--	--	--	--	--	--	15	15	14	4	10	4	11	6	6	6	3	13	11	118
01668000	Rappahannock River near Fredericksburg, VA	--	--	--	--	--	--	--	--	--	1	8	8	2	3	6	5	2	8	7	10	8	16	14	9	105
01669000	Piscataway Creek near Tappahannock, VA	--	--	--	--	--	--	--	--	--	--	--	4	18	12	12	11	5	5	12	10	8	7	14	11	129
01669520	Dragon Swamp at Mascot, VA	--	--	--	--	--	--	--	--	--	--	--	8	13	7	1	7	5	8	10	7	7	6	5	5	92
01670400	North Anna River near Partlow, VA	10	104	37	10	8	7	-	--	5	4	10	5	8	14	7	7	5	7	9	5	7	13	15	9	241
01671020	North Anna River at Hart Corner near Doswell, VA	--	--	--	--	--	--	--	--	5	--	--	--	--	14	1	6	5	9	9	7	6	4	14	7	121
01671025	North Anna River above Little River near Doswell, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5	4	11	10	10	10	33	12	102
01671100	Little River near Doswell, VA	--	--	--	--	--	--	--	--	--	--	--	22	18	11	4	44	4	10	7	5	5	9	12	6	157
01672500	South Anna River near Ashland, VA	--	--	--	--	--	--	3	4	--	--	--	--	--	3	1	1	2	3	5	11	13	11	13	9	79
01673000	Pamunkey River near Hanover, VA	--	--	--	--	--	--	--	8	12	12	6	9	4	10	4	3	9	3	8	5	13	7	14	5	132
01673550	Totopotomoy Creek near Studley, VA	3	9	--	12	11	5	12	9	14	13	8	10	15	8	6	13	21	10	6	3	10	8	13	8	227
01673800	Po River near Spotsylvania, VA	6	10	11	17	11	18	13	13	17	16	10	53	15	8	5	12	6	17	2	8	7	4	15	9	303
01674000	Mattaponi River near Bowling Green, VA	12	13	11	18	10	12	8	20	19	18	13	17	8	10	12	24	1	6	5	4	3	3	17	9	273
01674500	Mattaponi River near Beulahville, VA	--	--	--	--	--	3	9	8	7	15	11	8	11	6	6	5	5	5	2	6	8	12	13	6	146
02011400	Jackson River near Bacova, VA	--	--	--	1	--	4	6	5	6	9	6	10	7	0	2	5	2	3	6	6	2	4	4	1	89
02011460	Back Creek near Sunrise, VA	--	--	--	1	--	4	6	--	--	--	--	4	6	3	3	5	4	7	9	5	7	11	6	7	77
02011470	Back Creek at Sunrise, VA	--	--	--	--	1	3	16	8	0	0	8	5	1	1	0	4	1	2	5	6	5	8	8	6	88
02011490	Little Back Creek near Sunrise, VA	--	--	--	--	--	--	--	--	--	--	--	--	0	0	1	0	0	3	3	0	3	3	0	0	14
02011500	Back Creek near Mountain Grove, VA	--	--	--	--	--	7	12	8	28	14	10	5	4	4	2	4	2	6	6	8	9	9	12	4	155
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	--	--	--	--	--	3	6	6	2	0	0	2	3	0	0	0	0	1	0	8	0	7	4	2	38
02013000	Dunlap Creek near Covington, VA	--	--	--	--	--	3	15	7	13	12	8	18	16	7	2	6	5	8	7	8	7	10	15	6	173
02013100	Jackson River below Dunlap Creek at Covington, VA	--	--	--	--	--	3	0	0	4	15	7	7	9	4	4	8	4	5	5	4	6	7	10	0	102
02014000	Potts Creek near Covington, VA	--	--	--	--	--	3	10	4	9	10	10	11	7	5	4	6	5	7	6	8	9	12	12	4	142
02015700	Bullpasture River at Williamsville, VA	--	--	--	--	--	--	--	--	8	16	8	3	9	2	8	6	4	4	1	2	3	3	5	5	87
02016000	Cowpasture River near Clifton Forge, VA	--	--	--	--	--	--	--	--	--	2	1	8	8	1	3	1	0	4	5	2	6	4	0	2	47
02016500	James River at Lick Run, VA	--	--	--	--	--	--	--	--	2	6	4	5	9	4	2	4	2	5	1	3	6	3	5	4	65
02017500	Johns Creek at New Castle, VA	--	--	--	--	--	--	--	--	--	--	--	6	11	7	9	8	6	3	3	4	2	2	13	10	84
02018000	Craig Creek at Parr, VA	--	--	--	--	--	--	--	--	--	--	--	5	3	2	7	6	3	7	8	8	7	11	0	4	71
02018500	Catawba Creek near Catawba, VA	--	--	--	--	--	--	--	--	--	--	--	12	26	13	15	8	8	10	14	9	3	4	11	10	143
02019500	James River at Buchanan, VA	--	--	--	--	--	--	--	--	--	4	14	0	10	0	0	0	0	1	0	4	3	0	11	1	49
02020500	Calfpasture River above Mill Creek at Goshen, VA	--	--	--	--	--	--	--	--	2	13	0	6	10	4	7	5	8	8	5	10	4	5	12	7	106
02021500	Maury River at Rockbridge Baths, VA	--	--	--	--	--	--	2	2	4	12	6	7	2	7	2	3	4	3	6	9	9	9	11	4	102

Table 3   55

Table 3. Number of unique shifts recorded in the National Water Information System at streamgages in Virginia active as of September 30, 2013; includes multiple shifts begun on the same day.—Continued

[--, no shifts because data are unavailable for the period; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
02022500	Kerrs Creek near Lexington, VA	--	--	--	--	--	--	--	--	--	--	--	34	14	6	8	9	8	7	6	5	5	2	15	11	130
02024000	Maury River near Buena Vista, VA	--	--	--	--	--	--	--	--	--	--	5	9	6	3	2	2	6	2	6	2	7	10	5	2	68
02024752	James River at Blue Ridge Pkwy near Big Island, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5	7	7	5	3	1	8	10	46
02024915	Pedlar River at Forest Road near Buena Vista, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	3	3	4	5	15	4	2	3	2	16	8	65
02025500	James River at Holcomb Rock, VA	--	--	--	--	--	--	--	--	1	4	2	4	3	2	2	10	3	7	10	7	9	6	9	10	89
02026000	James River at Bent Creek, VA	--	--	--	--	--	--	--	--	--	--	--	5	4	1	2	6	2	5	7	9	9	4	7	11	72
02027000	Tye River near Lovingston, VA	--	--	--	--	--	--	--	--	3	4	14	4	11	3	4	4	3	6	6	3	2	3	14	7	91
02027500	Piney River at Piney River, VA	--	--	--	--	--	--	--	--	--	--	--	11	10	6	8	4	7	13	4	2	5	6	15	9	100
02028500	Rockfish River near Greenfield, VA	--	--	--	--	--	--	--	--	5	6	7	18	8	12	6	2	6	15	4	6	2	4	12	10	123
02029000	James River at Scottsville, VA	--	--	--	--	--	--	2	4	4	6	4	7	3	0	2	5	6	6	9	5	6	10	14	5	98
02030000	Hardware River below Briery Run near Scottsville, VA	12	--	--	--	--	--	--	6	6	8	13	16	48	28	10	8	4	9	2	2	6	6	11	7	190
02030500	Slate River near Arvonia, VA	--	19	14	14	8	14	--	--	6	--	--	--	22	6	--	9	6	12	13	6	2	4	16	7	148
02031000	Mechums River near White Hall, VA	--	--	--	--	--	--	--	--	--	--	--	8	22	6	14	7	7	20	7	9	5	4	13	6	129
02032250	Moormans River near Free Union, VA	--	--	--	--	--	--	--	--	--	6	--	--	8	--	6	--	6	19	6	9	10	5	13	13	82
02032640	North Fork Rivanna River near Earlysville, VA	--	--	--	1	11	19	9	2	2	25	10	17	11	9	10	6	6	11	30	8	14	6	17	8	232
02034000	Rivanna River at Palmyra, VA	2	--	--	--	--	--	--	--	--	--	--	10	9	5	6	8	9	5	9	6	9	2	13	10	101
02035000	James River at Cartersville, VA	--	2	--	6	4	--	--	1	--	--	--	5	10	6	1	3	4	6	11	5	10	10	16	9	115
02036500	Fine Creek at Fine Creek Mills, VA	14	27	21	24	17	13	12	20	14	27	18	20	31	10	8	26	15	14	15	16	10	8	19	5	404
02037000	James And Kanawha Canal near Richmond, VA	--	--	--	--	--	--	--	--	--	--	--	31	24	49	16	50	21	11	21	14	13	8	11	19	288
02037500	James River near Richmond, VA	--	--	--	--	--	--	--	1	--	4	4	0	8	0	2	8	3	4	4	3	5	2	6	2	56
02038850	Holiday Creek near Andersonville, VA	--	--	--	--	--	--	--	--	--	--	--	8	9	3	5	6	11	8	9	14	10	13	11	13	120
02039000	Buffalo Creek near Hampden Sydney, VA	7	31	15	23	16	14	16	13	12	8	9	18	8	11	15	12	9	7	9	4	4	1	16	9	287
02039500	Appomattox River at Farmville, VA	--	--	20	8	7	--	10	4	--	--	--	24	27	6	8	10	9	5	5	5	5	4	14	10	132
02040000	Appomattox River at Mattoax, VA	4	12	20	8	3	21	--	11	14	10	21	10	8	12	6	7	4	4	4	4	3	4	18	8	216
02040892	Appomattox River at Route 602 near Mannboro, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12	19	9	40
02041000	Deep Creek near Mannboro, VA	21	33	--	18	--	13	21	10	13	13	15	9	11	5	8	6	5	9	7	6	3	3	12	5	273
02041650	Appomattox River at Matoaca, VA	--	--	--	--	--	--	--	--	--	--	--	8	17	3	0	10	8	12	12	7	5	3	6	8	107
02042500	Chickahominy River near Providence Forge, VA	--	--	--	--	--	--	1	19	8	12	8	27	8	3	1	3	9	2	6	4	10	9	11	7	148
02044500	Nottoway River near Rawlings, VA	--	--	--	--	--	--	--	--	22	3	9	21	44	2	8	9	3	18	13	4	11	10	14	10	167
02045500	Nottoway River near Stony Creek, VA	4	18	12	10	11	18	12	16	17	4	14	9	16	14	19	14	11	11	3	4	4	8	15	8	267
02046000	Stony Creek near Dinwiddie, VA	--	--	--	--	--	--	--	--	--	--	--	13	34	8	10	30	15	18	14	16	11	2	15	9	195
02047000	Nottoway River near Sebrell, VA	--	--	--	--	--	--	--	--	--	--	1	3	12	10	2	4	2	2	8	7	6	10	10	11	88
02047500	Blackwater River near Dendron, VA	6	14	12	8	7	11	10	4	8	20	14	5	12	8	8	8	8	6	3	10	2	7	9	7	207
02049500	Blackwater River near Franklin, VA	--	--	--	--	--	--	--	1	10	14	12	5	4	6	4	1	2	2	2	8	6	10	14	13	114
02051000	North Meherrin River near Lunenburg, VA	--	--	--	--	--	--	--	--	8	8	14	27	12	10	4	7	6	19	6	2	7	5	16	5	156
02051500	Meherrin River near Lawrenceville, VA	--	--	--	--	--	--	2	5	4	8	6	8	4	5	3	3	2	6	7	10	8	12	12	6	111
02052000	Meherrin River at Emporia, VA	--	--	9	14	9	--	--	18	--	--	--	8	16	14	10	11	6	3	1	4	1	1	12	5	92
02053800	South Fork Roanoke River near Shawsville, VA	8	10	9	27	9	14	5	18	22	3	9	9	10	12	9	9	9	10	4	5	2	2	12	10	237
02054500	Roanoke River at Lafayette, VA	--	--	--	--	--	--	--	--	--	--	--	12	6	6	6	8	11	9	5	2	6	4	14	11	100
02054530	Roanoke River at Glenvar, VA	--	--	4	4	9	2	6	11	5	8	6	8	4	8	11	5	4	6	2	4	3	1	8	12	131

Table 3. Number of unique shifts recorded in the National Water Information System at streamgages in Virginia active as of September 30, 2013; includes multiple shifts begun on the same day.—Continued

[--, no shifts because data are unavailable for the period; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of unique shifts																								Total
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
02055000	Roanoke River at Roanoke, VA	--	--	--	--	--	--	--	--	--	--	3	7	13	0	3	1	2	6	7	3	12	10	5	2	74
02055100	Tinker Creek near Daleville, VA	--	--	--	--	--	--	--	5	15	20	10	15	14	9	7	10	6	9	9	7	9	8	6	1	161
02056000	Roanoke River at Niagara, VA	--	--	--	--	--	--	1	--	--	--	--	5	11	1	3	3	0	7	2	1	0	1	0	0	34
02056650	Back Creek near Dundee, VA	--	--	--	--	--	--	--	--	--	--	--	6	4	0	4	4	1	15	15	4	5	5	14	9	86
02056900	Blackwater River near Rocky Mount, VA	--	--	--	--	--	--	--	--	--	--	--	12	17	0	4	11	3	7	4	2	1	1	9	9	80
02058400	Pigg River near Sandy Level, VA	--	--	--	--	--	--	--	3	--	4	12	6	4	4	2	6	5	6	6	10	12	11	10	13	114
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	6	13	1	9	15	5	51
02059500	Goose Creek near Huddleston, VA	--	--	--	--	--	--	--	--	--	--	--	3	9	9	8	6	13	11	22	9	6	3	13	8	120
02060500	Roanoke River at Altavista, VA	--	--	--	--	--	--	7	6	5	3	5	8	2	1	1	7	2	3	1	4	5	7	8	13	89
02061000	Big Otter River near Bedford, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	7	2	4	4	12	8	8	47
02061500	Big Otter River near Evington, VA	--	--	--	--	--	--	--	--	--	--	--	15	15	6	4	8	13	9	7	2	5	4	11	10	111
02062500	Roanoke (Staunton) River at Brookneal, VA	--	6	18	6	--	3	8	1	6	18	8	12	13	3	3	5	2	2	6	5	6	11	12	7	135
02064000	Falling River near Naruna, VA	16	6	18	6	7	12	24	11	19	12	17	28	18	6	10	16	8	6	6	6	5	4	14	10	285
02065500	Cub Creek at Phenix, VA	--	--	--	--	--	--	--	--	2	10	12	11	15	8	6	13	10	12	12	12	8	8	12	10	161
02066000	Roanoke (Staunton) River at Randolph, VA	--	--	--	--	--	--	9	4	5	5	9	12	8	0	3	2	4	1	7	5	8	7	10	7	109
02069700	South Mayo River near Nettleridge, VA	--	--	--	--	--	--	--	--	--	--	--	8	9	10	4	11	4	2	1	2	1	2	8	6	68
02070000	North Mayo River near Spencer, VA	--	--	--	--	--	--	--	--	--	--	--	9	9	0	4	4	8	1	1	2	3	2	12	7	62
02071530	Smith River at Smith Riv Church near Woolwine, VA	--	--	--	--	--	--	--	5	6	6	9	16	11	5	8	17	8	3	5	4	2	4	9	9	127
02072000	Smith River near Philpott, VA	--	--	--	--	--	--	--	1	3	4	5	15	14	3	3	1	3	7	7	8	5	2	14	5	100
02072500	Smith River at Bassett, VA	--	--	--	--	--	3	2	2	5	2	4	9	2	1	1	5	2	6	8	7	3	6	15	5	88
02073000	Smith River at Martinsville, VA	--	--	--	--	--	--	1	--	--	--	--	1	8	11	12	6	7	6	8	6	8	4	7	4	88
02074500	Sandy River near Danville, VA	3	30	12	19	12	27	9	13	4	8	9	9	15	8	4	12	6	4	5	9	5	5	15	14	257
02075045	Dan River at Stp near Danville, VA	--	--	--	--	--	5	1	0	5	6	6	5	2	5	3	8	2	3	8	5	10	10	6	8	93
02075500	Dan River at Paces, VA	--	--	--	--	6	5	4	3	3	4	7	8	4	6	1	5	3	5	3	6	6	7	6	7	93
02077000	Banister River at Halifax, VA	--	--	7	1	6	7	5	1	3	0	1	6	4	2	0	4	3	1	3	5	4	4	13	14	91
02077500	Hyco River near Denniston, VA	--	--	--	--	--	--	1	9	8	20	20	15	10	5	1	6	7	9	2	7	6	9	10	13	158
02079640	Allen Creek near Boydton, VA	7	26	21	13	19	11	14	5	--	2	8	16	12	12	6	19	15	16	14	10	19	18	17	18	336
03164000	New River near Galax, VA	--	--	--	--	2	11	14	11	7	12	13	8	7	4	3	4	2	6	6	5	5	3	11	4	135
03165000	Chestnut Creek at Galax, VA	--	--	--	--	--	17	10	10	15	13	8	12	6	5	5	3	4	9	14	8	8	7	5	3	139
03165500	New River at Ivanhoe, VA	--	--	--	--	--	--	--	1	3	6	6	8	15	4	4	4	6	10	6	7	6	2	6	3	97
03167000	Reed Creek at Grahams Forge, VA	--	--	--	--	--	--	4	--	0	0	5	7	9	5	5	3	2	6	7	5	5	6	6	0	66
03168000	New River at Allisonia, VA	--	--	--	--	3	0	4	0	0	0	5	9	4	1	0	0	3	6	3	4	3	4	6	1	56
03170000	Little River at Graysontown, VA	--	--	--	--	1	--	--	2	7	9	1	4	14	7	10	7	6	10	9	5	2	3	9	4	91
03171000	New River at Radford, VA	--	--	--	--	1	4	0	2	7	9	9	12	10	4	2	2	1	7	3	2	1	0	0	5	81
03173000	Walker Creek at Bane, VA	--	--	--	8	1	0	5	9	4	9	12	11	11	7	4	4	2	5	7	6	5	4	7	7	120
03175500	Wolf Creek near Narrows, VA	--	--	--	--	4	18	5	7	19	20	15	12	13	4	4	7	5	6	4	5	3	5	7	3	166
03176500	New River at Glen Lyn, VA	--	--	--	--	1	11	14	5	18	8	4	0	6	0	1	0	3	7	1	5	9	3	5	5	106
03177710	Bluestone River at Falls Mills, VA	--	--	--	8	4	7	10	5	--	--	--	--	--	--	4	16	0	9	6	8	7	9	6	2	101
03207800	Levisa Fork at Big Rock, VA	--	--	--	--	1	9	12	6	5	4	4	13	11	5	6	6	6	5	8	5	7	10	10	3	134
03208500	Russell Fork at Haysi, VA	--	--	--	--	3	16	10	6	10	8	10	12	9	6	8	3	8	4	8	3	7	3	3	5	140

Table 3   57

Table 3.   Number of unique shifts recorded in the National Water Information System at streamgages in Virginia active as of September 30, 2013; includes multiple shifts begun on the same day.—Continued

[--, no shifts because data are unavailable for the period; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of unique shifts																							Total
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
03208950	Cranes Nest River near Clintwood, VA	--	--	--	--	4	16	8	9	12	9	54	14	16	6	5	6	2	8	11	8	15	14	17	5	239
03209000	Pound River below Flannagan Dam, near Haysi, VA	--	--	--	--	1	6	--	10	7	10	9	9	12	2	1	6	9	7	6	6	5	6	5	5	122
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	--	--	--	--	--	--	1	6	8	13	6	3	11	7	3	9	6	6	9	13	10	4	2	3	120
03473000	South Fork Holston River near Damascus, VA	--	--	--	--	--	--	1	3	9	8	10	13	7	6	3	2	4	4	3	3	1	5	4	5	91
03474000	Middle Fork Holston River at Seven Mile Ford, VA	--	--	--	--	--	--	1	8	10	4	11	11	14	4	5	8	5	3	6	7	8	8	8	1	122
03475000	Middle Fork Holston River near Meadowview, VA	--	--	--	--	--	--	3	8	8	13	12	9	10	5	5	6	2	5	7	2	5	6	5	1	112
03478400	Beaver Creek at Bristol, VA	--	--	--	--	--	--	3	4	15	12	9	15	8	6	5	4	4	5	9	5	6	4	18	4	136
03488000	North Fork Holston River near Saltville, VA	--	--	--	--	--	--	1	4	12	15	11	9	6	11	2	9	3	6	9	6	9	7	10	4	134
03490000	North Fork Holston River near Gate City, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	2
03524000	Clinch River at Cleveland, VA	--	--	--	--	--	3	8	3	0	12	11	7	7	0	3	4	5	6	10	3	10	7	8	5	112
03524500	Guest River at Coeburn, VA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	3
03527000	Clinch River at Speers Ferry, VA	--	--	--	--	--	--	--	--	--	--	--	2	4	0	4	7	3	3	4	3	1	3	1	5	40
03529500	Powell River at Big Stone Gap, VA	--	--	--	--	--	--	--	--	--	--	--	2	11	5	6	4	5	7	9	6	10	7	8	7	87
03531500	Powell River near Jonesville, VA	--	--	--	--	--	1	10	10	10	14	6	11	4	4	4	6	1	6	7	5	2	7	5	2	115
Total		214	539	384	419	342	599	520	605	783	913	959	1,559	1,635	996	899	1,183	880	1,294	1,345	1,186	1,194	1,190	2,081	1,407	23,126

Table 4. Number of base ratings and number of days they were in effect for streamgages in Virginia, water years 1991–2013, for periods when the ratings were stored in the National Water Information System.

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of base ratings available	Number of days those ratings were in effect	Average days per rating
01613900	Hogue Creek near Hayfield, VA	2	5,312	2,656
01615000	Opequon Creek near Berryville, VA	9	6,594	733
01616100	Dry Marsh Run near Berryville, VA	1	4,061	4,061
01620500	North River near Stokesville, VA	6	5,741	957
01621050	Muddy Creek at Mount Clinton, VA	4	6,576	1,644
01622000	North River near Burketown, VA	1	5,845	5,845
01625000	Middle River near Grottoes, VA	3	8,402	2,801
01626000	South River near Waynesboro, VA	2	8,402	4,201
01626850	South River near Dooms, VA	6	5,257	876
01627500	South River at Harriston, VA	2	5,745	2,873
01628500	South Fork Shenandoah River near Lynnwood, VA	2	8,402	4,201
01629500	South Fork Shenandoah River near Luray, VA	4	5,115	1,279
01631000	South Fork Shenandoah River at Front Royal, VA	3	8,402	2,801
01632000	North Fork Shenandoah River at Cootes Store, VA	7	6,234	891
01632082	Linville Creek at Broadway, VA	4	8,402	2,101
01632900	Smith Creek near New Market, VA	6	8,402	1,400
01633000	North Fork Shenandoah River at Mount Jackson, VA	1	5,312	5,312
01634000	North Fork Shenandoah River near Strasburg, VA	4	8,402	2,101
01634500	Cedar Creek near Winchester, VA	3	8,402	2,801
01635500	Passage Creek near Buckton, VA	2	8,402	4,201
01636316	Spout Run at Rt 621 near Millwood, VA	2	4,059	2,029
01636690	Piney Run near Lovettsville, VA	4	4,445	1,111
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	4	4,480	1,120
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	4	4,457	1,114
01638480	Catoctin Creek at Taylorstown, VA	2	5,807	2,904
01643590	Limestone Branch near Leesburg, VA	4	4,424	1,106
01643700	Goose Creek near Middleburg, VA	8	6,616	827
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	6	4,458	743
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	9	4,460	496
01644000	Goose Creek near Leesburg, VA	2	5,673	2,837
01644280	Broad Run near Leesburg, VA	6	4,414	736
01645704	Difficult Run above Fox Lake near Fairfax, VA	4	2,203	551
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	5	2,204	441
01646000	Difficult Run near Great Falls, VA	6	8,402	1,400
01646305	Dead Run at Whann Avenue near Mclean, VA	3	2,092	697
01652500	Fourmile Run at Alexandria, VA	4	8,402	2,101
01653000	Cameron Run at Alexandria, VA	5	6,941	1,388
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	2	714	357
01654000	Accotink Creek near Annandale, VA	4	5,821	1,455
01656000	Cedar Run near Catlett, VA	5	8,402	1,680
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	5	2,204	441
01658500	South Fork Quantico Creek near Independent Hill, VA	4	6,576	1,644
01660400	Aquia Creek near Garrisonville, VA	4	5,716	1,429
01662800	Battle Run near Laurel Mills, VA	7	7,588	1,084
01663500	Hazel River at Rixeyville, VA	6	4,402	734

Table 4   59

Table 4. Number of base ratings and number of days they were in effect for streamgages in Virginia, water years 1991–2013, for periods when the ratings were stored in the National Water Information System.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of base ratings available	Number of days those ratings were in effect	Average days per rating
01664000	Rappahannock River at Remington, VA	3	5,745	1,915
01665500	Rapidan River near Ruckersville, VA	4	5,483	1,371
01666500	Robinson River near Locust Dale, VA	2	8,402	4,201
01667500	Rapidan River near Culpeper, VA	1	5,314	5,314
01668000	Rappahannock River near Fredericksburg, VA	5	8,402	1,680
01669000	Piscataway Creek near Tappahannock, VA	2	4,536	2,268
01669520	Dragon Swamp at Mascot, VA	2	5,718	2,859
01670400	North Anna River near Partlow, VA	5	4,206	841
01671020	North Anna River at Hart Corner near Doswell, VA	5	8,402	1,680
01671025	North Anna River above Little River near Doswell, VA	2	3,381	1,691
01671100	Little River near Doswell, VA	1	5,359	5,359
01672500	South Anna River near Ashland, VA	4	6,305	1,576
01673000	Pamunkey River near Hanover, VA	6	7,248	1,208
01673550	Totopotomoy Creek near Studley, VA	8	8,402	1,050
01673800	Po River near Spotsylvania, VA	5	8,402	1,680
01674000	Mattaponi River near Bowling Green, VA	4	8,402	2,101
01674500	Mattaponi River near Beulahville, VA	4	8,402	2,101
02011400	Jackson River near Bacova, VA	2	8,037	4,019
02011460	Back Creek near Sunrise, VA	6	5,746	958
02011470	Back Creek at Sunrise, VA	8	8,402	1,050
02011490	Little Back Creek near Sunrise, VA	4	8,402	2,101
02011500	Back Creek near Mountain Grove, VA	3	7,306	2,435
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	4	7,185	1,796
02013000	Dunlap Creek near Covington, VA	4	8,402	2,101
02013100	Jackson River below Dunlap Creek at Covington, VA	4	8,402	2,101
02014000	Potts Creek near Covington, VA	4	7,241	1,810
02015700	Bullpasture River at Williamsville, VA	2	6,466	3,233
02016000	Cowpasture River near Clifton Forge, VA	5	7,671	1,534
02016500	James River at Lick Run, VA	2	7,671	3,836
02017500	Johns Creek at New Castle, VA	1	7,241	7,241
02018000	Craig Creek at Parr, VA	3	7,240	2,413
02018500	Catawba Creek near Catawba, VA	2	5,706	2,853
02019500	James River at Buchanan, VA	2	6,576	3,288
02020500	Calfpasture River above Mill Creek at Goshen, VA	4	5,480	1,370
02021500	Maury River at Rockbridge Baths, VA	3	8,402	2,801
02022500	Kerrs Creek near Lexington, VA	1	4,943	4,943
02024000	Maury River near Buena Vista, VA	3	7,671	2,557
02024752	James River at Blue Ridge Pkwy near Big Island, VA	3	3,038	1,013
02024915	Pedlar River at Forest Road near Buena Vista, VA	5	3,984	797
02025500	James River at Holcomb Rock, VA	4	8,402	2,101
02026000	James River at Bent Creek, VA	5	8,402	1,680
02027000	Tye River near Lovingston, VA	5	5,746	1,149
02027500	Piney River at Piney River, VA	3	5,270	1,757
02028500	Rockfish River near Greenfield, VA	3	7,241	2,414
02029000	James River at Scottsville, VA	3	8,402	2,801

Table 4.   Number of base ratings and number of days they were in effect for streamgages in Virginia, water years 1991–2013, for periods when the ratings were stored in the National Water Information System.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of base ratings available	Number of days those ratings were in effect	Average days per rating
02030000	Hardware River below Briery Run near Scottsville, VA	3	8,045	2,682
02030500	Slate River near Arvonia, VA	2	4,863	2,432
02031000	Mechums River near White Hall, VA	2	7,160	3,580
02032250	Moormans River near Free Union, VA	5	5,565	1,113
02032640	North Fork Rivanna River near Earlysville, VA	4	7,306	1,827
02034000	Rivanna River at Palmyra, VA	2	5,364	2,682
02035000	James River at Cartersville, VA	2	8,402	4,201
02036500	Fine Creek at Fine Creek Mills, VA	5	8,402	1,680
02037000	James River And Kanawha Canal near Richmond, VA	3	7,306	2,435
02037500	James River near Richmond, VA	4	6,202	1,550
02038850	Holiday Creek near Andersonville, VA	3	5,115	1,705
02039000	Buffalo Creek near Hampden Sydney, VA	4	8,402	2,101
02039500	Appomattox River at Farmville, VA	1	4,384	4,384
02040000	Appomattox River at Mattoax, VA	4	8,402	2,101
02040892	Appomattox River at Route 602 near Mannboro, VA	2	833	417
02041000	Deep Creek near Mannboro, VA	6	8,402	1,400
02041650	Appomattox River at Matoaca, VA	3	7,243	2,414
02042500	Chickahominy River near Providence Forge, VA	8	7,306	913
02044500	Nottoway River near Rawlings, VA	1	4,915	4,915
02045500	Nottoway River near Stony Creek, VA	7	7,569	1,081
02046000	Stony Creek near Dinwiddie, VA	2	4,577	2,288
02047000	Nottoway River near Sebrell, VA	6	5,714	952
02047500	Blackwater River near Dendron, VA	6	8,402	1,400
02049500	Blackwater River near Franklin, VA	9	8,402	934
02051000	North Meherrin River near Lunenburg, VA	3	5,719	1,906
02051500	Meherrin River near Lawrenceville, VA	3	8,402	2,801
02052000	Meherrin River at Emporia, VA	3	5,738	1,913
02053800	South Fork Roanoke River near Shawsville, VA	7	8,402	1,200
02054500	Roanoke River at Lafayette, VA	2	4,915	2,457
02054530	Roanoke River at Glenvar, VA	2	7,965	3,983
02055000	Roanoke River at Roanoke, VA	3	7,127	2,376
02055100	Tinker Creek near Daleville, VA	2	7,306	3,653
02056000	Roanoke River at Niagara, VA	2	7,671	3,836
02056650	Back Creek near Dundee, VA	3	5,115	1,705
02056900	Blackwater River near Rocky Mount, VA	2	6,835	3,417
02058400	Pigg River near Sandy Level, VA	4	8,402	2,101
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	4	2,559	640
02059500	Goose Creek near Huddleston, VA	2	6,576	3,288
02060500	Roanoke River at Altavista, VA	3	8,402	2,801
02061000	Big Otter River near Bedford, VA	3	2,488	829
02061500	Big Otter River near Evington, VA	2	7,240	3,620
02062500	Roanoke (Staunton) River at Brookneal, VA	4	7,671	1,918
02064000	Falling River near Naruna, VA	5	8,402	1,680
02065500	Cub Creek at Phenix, VA	1	7,247	7,247
02066000	Roanoke (Staunton) River at Randolph, VA	2	8,402	4,201

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Table 4. Number of base ratings and number of days they were in effect for streamgages in Virginia, water years 1991–2013, for periods when the ratings were stored in the National Water Information System.—Continued

[VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of base ratings available	Number of days those ratings were in effect	Average days per rating
02069700	South Mayo River near Nettleridge, VA	1	4,943	4,943
02070000	North Mayo River near Spencer, VA	1	7,241	7,241
02071530	Smith River at Smith Riv Church near Woolwine, VA	6	6,922	1,154
02072000	Smith River near Philpott, VA	4	8,402	2,101
02072500	Smith River at Bassett, VA	6	8,402	1,400
02073000	Smith River at Martinsville, VA	2	7,128	3,564
02074500	Sandy River near Danville, VA	2	8,402	4,201
02075045	Dan River at Stp near Danville, VA	5	7,306	1,461
02075500	Dan River at Paces, VA	1	2,876	2,876
02077000	Banister River at Halifax, VA	5	8,290	1,658
02077500	Hyco River near Denniston, VA	5	5,840	1,168
02079640	Allen Creek near Boydton, VA	5	6,960	1,392
03164000	New River near Galax, VA	4	8,037	2,009
03165000	Chestnut Creek at Galax, VA	3	8,402	2,801
03165500	New River at Ivanhoe, VA	5	6,148	1,230
03167000	Reed Creek at Grahams Forge, VA	2	7,789	3,894
03168000	New River at Allisonia, VA	2	7,617	3,808
03170000	Little River at Graysontown, VA	4	8,037	2,009
03171000	New River at Radford, VA	2	8,402	4,201
03173000	Walker Creek at Bane, VA	6	7,496	1,249
03175500	Wolf Creek near Narrows, VA	3	8,035	2,678
03176500	New River at Glen Lyn, VA	4	7,496	1,874
03177710	Bluestone River at Falls Mills, VA	5	4,792	958
03207800	Levisa Fork at Big Rock, VA	6	8,402	1,400
03208500	Russell Fork at Haysi, VA	4	8,402	2,101
03208950	Cranes Nest River near Clintwood, VA	5	8,402	1,680
03209000	Pound River below Flannagan Dam, near Haysi, VA	4	8,402	2,101
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	3	7,587	2,529
03473000	South Fork Holston River near Damascus, VA	5	7,173	1,435
03474000	Middle Fork Holston River at Seven Mile Ford, VA	1	8,402	8,402
03475000	Middle Fork Holston River near Meadowview, VA	2	7,942	3,971
03478400	Beaver Creek at Bristol, VA	5	8,037	1,607
03488000	North Fork Holston River near Saltville, VA	3	8,402	2,801
03490000	North Fork Holston River near Gate City, VA	1	549	549
03524000	Clinch River at Cleveland, VA	3	7,587	2,529
03524500	Guest River at Coeburn, VA	2	427	214
03527000	Clinch River at Speers Ferry, VA	6	4,384	731
03529500	Powell River at Big Stone Gap, VA	3	4,384	1,461
03531500	Powell River near Jonesville, VA	3	6,941	2,314
	Total	**643**	**1,140,402**	**1,774**

Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.

[GAM, generalized additive model; R², coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; *Italicized text* represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R² of GAM of gage height as a function of flow	R² of GAM of flow as a function of gage height	Explanation
01613900	Hogue Creek near Hayfield, VA	01613900_RF1	No	10/6/1980	4/14/2009	185	0.8426	0.8581	0.8575	First RatFam at site
		01613900_RF2	Yes	6/2/2009	9/4/2013	29	0.7824	0.7881	0.7949	Backwater from rock pile
01615000	Opequon Creek near Berryville, VA	01615000_RF1	No	10/16/1940	12/2/1997	525	0.8069	0.8768	0.7990	First RatFam at site
		01615000_RF2	Yes	10/15/2002	10/22/2013	86	0.9094	0.3266	0.8446	Moved gage
01616100	Dry Marsh Run near Berryville, VA	01616100_RF1	Yes	8/21/2002	10/21/2013	83	0.9267	0.9080	0.9009	First RatFam at site
01620500	North River near Stokesville, VA	*01620500_RF1*	No	*12/4/1945*	*5/14/1958*	*163*	*0.7013*	*0.5888*	*0.6009*	*First RatFam at site*
		01620500_RF2	No	*6/10/1958*	*10/24/1985*	*268*	*0.9278*	*0.7488*	*0.7725*	*Moved gage and changed datum*
		01620500_RF3	No	11/5/1985	4/18/1996	83	0.8386	0.5657	0.6338	Moved gage and changed datum
		01620500_RF4	Yes	6/3/1996	10/24/2013	133	0.5819	0.2853	0.2875	Moved gage and changed datum
01621050	Muddy Creek at Mount Clinton, VA	01621050_RF1	Yes	1/28/1993	10/24/2013	204	0.9295	0.9622	0.8750	First RatFam at site
01622000	North River near Burketown, VA	*01622000_RF1*	No	*6/1/1926*	*8/24/1938*	*48*	*0.9971*	*0.9983*	*0.9956*	*First RatFam at site*
		01622000_RF2	Yes	10/26/1938	9/3/2013	567	0.9763	0.9886	0.9760	Moved gage
01625000	Middle River near Grottoes, VA	*01625000_RF1*	No	*2/8/1925*	*1/18/1966*	*330*	*0.9888*	*0.9938*	*0.9902*	*First RatFam at site*
		01625000_RF2	Yes	5/24/1966	9/18/2013	370	0.8753	0.8948	0.8422	Graphical appearance
01626000	South River near Waynesboro, VA	01626000_RF1	Yes	11/17/1981	9/18/2013	227	0.9825	0.9943	0.9819	First RatFam at site
01626850	South River near Dooms, VA	*01626850_RF1*	No	*4/17/1974*	*9/30/1985*	*122*	*0.9372*	*0.9682*	*0.9564*	*First RatFam at site*
		01626850_RF2	No	1/10/1986	10/11/1996	90	0.9509	0.9896	0.9706	Control changed by November 1985 flood
		01626850_RF3	Yes	7/20/2005	9/18/2013	73	0.9197	0.9669	0.9390	Data gap
01627500	South River at Harriston, VA	01627500_RF1	Yes	2/16/1925	9/18/2013	442	0.7833	0.8581	0.8174	First RatFam at site
01628500	South Fork Shenandoah River near Lynnwood, VA	01628500_RF1	Yes	9/18/1930	10/24/2013	616	0.9891	0.9938	0.9862	First RatFam at site
01629500	South Fork Shenandoah River near Luray, VA	01629500_RF1	Yes	4/26/1925	10/22/2013	393	0.9460	0.9607	0.9436	First RatFam at site
01631000	South Fork Shenandoah River at Front Royal, VA	01631000_RF1	Yes	7/12/1930	10/22/2013	665	0.9697	0.9785	0.9697	First RatFam at site
01632000	North Fork Shenandoah River at Cootes Store, VA	*01632000_RF1*	No	*2/28/1925*	*2/6/1942*	*81*	*0.9605*	*0.9750*	*0.9155*	*First RatFam at site*
		01632000_RF2	No	*3/13/1942*	*7/30/1946*	*63*	*0.8557*	*0.8676*	*0.8236*	*Apparent attempt to build a rock dam/control*
		01632000_RF3	No	*8/8/1946*	*2/25/1960*	*136*	*0.9579*	*0.9420*	*0.9202*	*Concrete weir installed*
		01632000_RF4	No	*4/5/1960*	*10/25/1985*	*207*	*0.9979*	*0.9970*	*0.9946*	*Graphical appearance*
		01632000_RF5	No	2/3/1986	7/31/1996	78	0.9685	0.9613	0.9145	Control changed by November 1985 flood
		01632000_RF6	Yes	9/6/1996	10/23/2013	119	0.9165	0.9578	0.8601	Control changed by September 1996 flood
01632082	Linville Creek at Broadway, VA	01632082_RF1	No	8/9/1985	1/17/1996	100	0.8740	0.9482	0.9055	First RatFam at site
		01632082_RF2	Yes	1/19/1996	9/3/2013	136	0.9459	0.9842	0.9631	Control changed by January 1996 flood
01632900	Smith Creek near New Market, VA	*01632900_RF1*	No	*8/19/1960*	*7/8/1963*	*47*	*0.9602*	*0.9784*	*0.9717*	*First RatFam at site*
		01632900_RF2	Yes	8/2/1963	10/23/2013	413	0.8754	0.9559	0.8589	Moved gage
01633000	North Fork Shenandoah River at Mount Jackson, VA	01633000_RF1	Yes	1/11/1989	10/22/2013	180	0.9932	0.9964	0.9895	First RatFam at site
01634000	North Fork Shenandoah River near Strasburg, VA	*01634000_RF1*	No	*3/6/1925*	*10/17/1942*	*93*	*0.9925*	*0.9985*	*0.9945*	*First RatFam at site*
		01634000_RF2	Yes	11/5/1942	10/23/2013	580	0.9854	0.9916	0.9822	Control changed by October 1942 flood
01634500	Cedar Creek near Winchester, VA	01634500_RF1	Yes	10/15/1942	10/22/2013	198	0.9691	0.9895	0.9696	First RatFam at site
01635500	Passage Creek near Buckton, VA	01635500_RF1	Yes	10/15/1942	10/22/2013	173	0.9873	0.9895	0.9844	First RatFam at site
01636316	Spout Run at Rt 621 near Millwood, VA	01636316_RF1	Yes	8/22/2002	10/21/2013	84	0.8416	0.9267	0.8619	First RatFam at site
01636690	Piney Run near Lovettsville, VA	01636690_RF1	Yes	8/2/2001	11/6/2013	89	0.9242	0.9204	0.8676	First RatFam at site
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	01638350_RF1	Yes	8/2/2001	11/6/2013	92	0.9217	0.9433	0.8937	First RatFam at site
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	01638420_RF1	Yes	8/2/2001	11/6/2013	88	0.9750	0.9837	0.9473	First RatFam at site
01638480	Catoctin Creek at Taylorstown, VA	*01638480_RF1*	No	*8/4/1971*	*9/27/1983*	*120*	*0.9643*	*0.9710*	*0.9565*	*First RatFam at site*
		01638480_RF2	Yes	11/3/1983	8/21/2013	251	0.9290	0.9658	0.8529	Moved gage and changed datum
01643590	Limestone Branch near Leesburg, VA	01643590_RF1	Yes	9/6/2001	11/6/2013	94	0.9721	0.9889	0.9761	First RatFam at site
01643700	Goose Creek near Middleburg, VA	01643700_RF1	Yes	2/2/1970	11/7/2013	176	0.9793	0.9873	0.9407	First RatFam at site
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	01643805_RF1	Yes	8/2/2001	11/7/2013	95	0.9438	0.9717	0.8952	First RatFam at site
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	01643880_RF1	Yes	8/2/2001	11/7/2013	90	0.9358	0.9495	0.8339	First RatFam at site

Table 9   63

Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

[GAM, generalized additive model; R^2, coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; *Italicized text* represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R^2 of GAM of gage height as a function of flow	R^2 of GAM of flow as a function of gage height	Explanation
01644000	Goose Creek near Leesburg, VA	*01644000_RF1*	*No*	*1/21/1930*	*9/15/1938*	*42*	*0.9767*	*0.9927*	*0.9764*	*First RatFam at site*
		01644000_RF2	*No*	*2/4/1939*	*8/3/1970*	*350*	*0.9787*	*0.9665*	*0.9385*	*Moved gage and changed datum*
		01644000_RF3	*No*	*9/12/1977*	*10/5/1982*	*47*	*0.9537*	*0.9863*	*0.9408*	*Data gap*
		01644000_RF4	Yes	11/16/1988	10/22/2013	198	0.9892	0.9781	0.9480	Data gap
01644280	Broad Run near Leesburg, VA	01644280_RF1	Yes	11/30/2001	11/5/2013	87	0.9507	0.9295	0.9421	First RatFam at site
01645704	Difficult Run above Fox Lake near Fairfax, VA	01645704_RF1	Yes	9/27/2007	9/17/2013	61	0.9334	0.9843	0.9530	First RatFam at site
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	01645762_RF1	No	9/27/2007	8/30/2011	41	0.8447	0.8906	0.8599	First RatFam at site
		01645762_RF2	Yes	9/12/2011	9/18/2013	19	0.9377	0.9771	0.9932	Control changed by flood
01646000	Difficult Run near Great Falls, VA	01646000_RF1	Yes	2/12/1935	9/17/2013	714	0.9827	0.9839	0.9729	First RatFam at site
01646305	Dead Run at Whann Avenue near Mclean, VA	01646305_RF1	Yes	1/9/2008	9/17/2013	56	0.7886	0.9232	0.8711	First RatFam at site
01652500	Fourmile Run at Alexandria, VA	*01652500_RF1*	*No*	*6/6/1951*	*8/20/1973*	*130*	*0.7795*	*0.8480*	*0.8947*	*First RatFam at site*
		01652500_RF2	Yes	10/29/1990	9/16/2013	125	0.7080	0.3223	0.8181	Moved gage
01653000	Cameron Run at Alexandria, VA	*01653000_RF1*	*No*	*6/24/1955*	*11/4/1975*	*324*	*0.4209*	*0.5222*	*0.5683*	*First RatFam at site*
		01653000_RF2	*No*	*11/9/1976*	*3/7/1979*	*27*	*0.8102*	*0.1581*	*0.9233*	*Moved gage*
		01653000_RF3	*No*	*11/8/1979*	*6/21/1983*	*30*	*0.8272*	*0.2117*	*0.8418*	*Moved gage back to original location and changed datum*
		01653000_RF4	No	1/3/1984	2/27/1986	22	0.3524	0.1458	0.4205	Graphical appearance
		01653000_RF5	Yes	3/27/1986	9/16/2013	251	0.6614	0.6311	0.6664	Data gap
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	0165389205_RF1	Yes	10/19/2011	9/17/2013	23	0.9842	0.9960	0.9924	First RatFam at site
01654000	Accotink Creek near Annandale, VA	*01654000_RF1*	*No*	*11/25/1943*	*4/29/1970*	*283*	*0.8504*	*0.9478*	*0.8690*	*First RatFam at site*
		01654000_RF2	*No*	*6/4/1970*	*7/3/1975*	*60*	*0.9298*	*0.9862*	*0.9601*	*Moved gage*
		01654000_RF3	*No*	*8/7/1975*	*12/12/1977*	*25*	*0.9906*	*0.9993*	*0.9908*	*Graphical appearance*
		01654000_RF4	Yes	1/30/1978	9/16/2013	297	0.7315	0.8313	0.6026	Graphical appearance
01656000	Cedar Run near Catlett, VA	01656000_RF1	Yes	12/4/1950	9/5/2013	196	0.9754	0.9887	0.9374	First RatFam at site
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	01656903_RF1	Yes	9/27/2007	9/18/2013	63	0.9857	0.9964	0.9872	First RatFam at site
01658500	South Fork Quantico Creek near Independent Hill, VA	*01658500_RF1*	*No*	*5/11/1951*	*10/26/1988*	*372*	*0.8521*	*0.9160*	*0.7401*	*First RatFam at site*
		01658500_RF2	No	1/24/1990	11/5/2013	219	0.8986	0.9372	0.8486	Control changed by flood
01660400	Aquia Creek near Garrisonville, VA	01660400_RF1	No	8/30/1971	10/16/1997	235	0.6973	0.6948	0.5426	First RatFam at site
		01660400_RF2	Yes	12/1/1997	11/5/2013	124	0.9236	0.5582	0.4969	Data gap/hiatus
01662800	Battle Run near Laurel Mills, VA	01662800_RF1	No	9/2/1958	6/12/1995	406	0.7945	0.8302	0.7207	First RatFam at site
		01662800_RF2	Yes	10/3/1997	9/19/2013	117	0.9893	0.5851	0.6708	Moved gage
01663500	Hazel River at Rixeyville, VA	01663500_RF1	Yes	7/27/1942	11/4/2013	543	0.9797	0.9786	0.9180	First RatFam at site
01664000	Rappahannock River at Remington, VA	01664000_RF1	Yes	12/15/1942	11/4/2013	601	0.9869	0.9905	0.9626	First RatFam at site
01665500	Rapidan River near Ruckersville, VA	01665500_RF1	No	8/31/1989	5/24/1995	55	0.7228	0.8717	0.6584	First RatFam at site
		01665500_RF2	Yes	9/2/1998	10/30/2013	127	0.9868	0.9837	0.9549	Moved gage
01666500	Robinson River near Locust Dale, VA	01666500_RF1	Yes	6/8/1984	9/19/2013	208	0.9764	0.9551	0.9470	First RatFam at site
01667500	Rapidan River near Culpeper, VA	01667500_RF1	Yes	10/16/1942	9/19/2013	201	0.9920	0.9819	0.9864	First RatFam at site
01668000	Rappahannock River near Fredericksburg, VA	01668000_RF1	No	9/12/1907	10/24/2000	557	0.9937	0.9926	0.9901	First RatFam at site
		01668000_RF2	Yes	12/18/2000	10/22/2013	81	0.9741	0.9761	0.9568	Moved gage
01669000	Piscataway Creek near Tappahannock, VA	01669000_RF1	No	6/8/1951	4/7/1999	407	0.7667	0.5727	0.5808	First RatFam at site
		01669000_RF2	No	6/11/1999	2/1/2005	50	0.8205	0.5075	0.5657	Control changed by flood
		01669000_RF3	Yes	4/5/2005	9/16/2013	60	0.9564	0.7694	0.7292	Graphical appearance
01669520	Dragon Swamp at Mascot, VA	01669520_RF1	Yes	4/7/1981	8/14/2013	227	0.9559	0.9133	0.8895	First RatFam at site

Table 9.   Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

[GAM, generalized additive model; R², coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; *Italicized text* represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R² of GAM of gage height as a function of flow	R² of GAM of flow as a function of gage height	Explanation
01670400	North Anna River near Partlow, VA	*01670400_RF1*	*No*	*1/18/1972*	*8/3/1972*	*20*	*0.9830*	*0.9049*	*0.9978*	*First RatFam at site*
		01670400_RF2	*No*	*5/28/1975*	*9/17/1984*	*82*	*0.7659*	*0.9819*	*0.9493*	*Graphical appearance, but apparent change in measurement frequency prior to establishment as a continuous gage*
		01670400_RF3	Yes	10/25/1984	10/22/2013	139	0.8692	0.9387	0.8926	Moved gage
01671020	North Anna River at Hart Corner near Doswell, VA	01671020_RF1	Yes	10/24/1979	10/16/2013	321	0.9691	0.9897	0.9829	First RatFam at site
01671025	North Anna River above Little River near Doswell, VA	01671025_RF1	Yes	10/8/2004	10/29/2013	76	0.9767	0.9726	0.9767	First RatFam at site
01671100	Little River near Doswell, VA	01671100_RF1	Yes	11/9/1988	9/16/2013	164	0.9922	0.9821	0.9677	First RatFam at site
01672500	South Anna River near Ashland, VA	01672500_RF1	Yes	10/18/1930	10/29/2013	629	0.9889	0.9891	0.9832	First RatFam at site
01673000	Pamunkey River near Hanover, VA	01673000_RF1	Yes	10/23/1941	10/29/2013	696	0.9887	0.9803	0.9753	First RatFam at site
01673550	Totopotomoy Creek near Studley, VA	*01673550_RF1*	*No*	*11/3/1977*	*8/10/1987*	*88*	*0.9374*	*0.9480*	*0.8830*	*First RatFam at site*
		01673550_RF2	Yes	11/15/1988	9/17/2013	209	0.9493	0.9473	0.8690	Data gap/hiatus
01673800	Po River near Spotsylvania, VA	01673800_RF1	Yes	9/24/1962	9/16/2013	454	0.9654	0.9450	0.8917	First RatFam at site
01674000	Mattaponi River near Bowling Green, VA	01674000_RF1	Yes	1/19/1961	10/21/2013	457	0.9911	0.9802	0.9063	First RatFam at site
01674500	Mattaponi River near Beulahville, VA	01674500_RF1	Yes	9/19/1941	10/29/2013	649	0.9951	0.9899	0.9886	First RatFam at site
02011400	Jackson River near Bacova, VA	*02011400_RF1*	*No*	*6/21/1974*	*11/4/1985*	*89*	*0.9823*	*0.9929*	*0.9850*	*First RatFam at site*
		02011400_RF2	Yes	11/21/1985	10/30/2013	216	0.9713	0.9653	0.9595	Control changed by November 1985 flood
02011460	Back Creek near Sunrise, VA	*02011460_RF1*	*No*	*5/7/1974*	*12/14/1977*	*40*	*0.9806*	*0.9946*	*0.9912*	*First RatFam at site*
		02011460_RF2	*No*	*1/31/1978*	*11/6/1985*	*65*	*0.9918*	*0.9894*	*0.9856*	*Control changed by flood*
		02011460_RF3	*No*	*4/9/1986*	*2/10/2004*	*157*	*0.9735*	*0.9535*	*0.9549*	Control changed by November 1985 flood, and only stabilized in April 1986
		02011460_RF4	No	4/6/2004	10/7/2008	37	0.9970	0.9152	0.9084	Graphical appearance
		02011460_RF5	Yes	11/13/2008	10/30/2013	38	0.9915	0.9847	0.9839	Graphical appearance
02011470	Back Creek at Sunrise, VA	02011470_RF1	Yes	9/21/1984	10/30/2013	272	0.9820	0.9407	0.9698	First RatFam at site
02011490	Little Back Creek near Sunrise, VA	02011490_RF1	Yes	9/19/1984	10/30/2013	68	0.9227	0.9858	0.9874	First RatFam at site
02011500	Back Creek near Mountain Grove, VA	*02011500_RF1*	*No*	*9/26/1951*	*12/4/1973*	*259*	*0.9449*	*0.9510*	*0.9079*	*First RatFam at site*
		02011500_RF2	Yes	1/4/1974	10/30/2013	333	0.9515	0.9524	0.9344	Control changed by flood
02011800	Jackson River below Gathright Dam near Hot Spgs., VA	02011800_RF1	Yes	10/19/1973	10/30/2013	378	0.9863	0.9938	0.9871	First RatFam at site
02013000	Dunlap Creek near Covington, VA	*02013000_RF1*	*No*	*12/14/1928*	*8/18/1969*	*353*	*0.9734*	*0.9778*	*0.9735*	*First RatFam at site*
		02013000_RF2	*No*	*8/20/1969*	*2/14/1973*	*33*	*0.9106*	*0.9740*	*0.9384*	*Control changed by 1969 flood*
		02013000_RF3	*No*	*4/3/1973*	*1/9/1986*	*102*	*0.9783*	*0.9676*	*0.9641*	*Control changed by June 1972 flood from Hurricane Agnes and only stabilized in April 1973*
		02013000_RF4	Yes	2/21/1986	10/29/2013	228	0.9536	0.9556	0.9447	Control changed by November 1985 flood, and only stabilized in February 1986
02013100	Jackson River below Dunlap Creek at Covington, VA	02013100_RF1	Yes	9/20/1974	10/29/2013	338	0.9630	0.9942	0.9783	First RatFam at site
02014000	Potts Creek near Covington, VA	*02014000_RF1*	*No*	*12/14/1928*	*9/9/1953*	*192*	*0.9937*	*0.9939*	*0.9919*	*First RatFam at site*
		02014000_RF2	*No*	*10/6/1953*	*10/17/1956*	*41*	*0.9762*	*0.9971*	*0.9951*	Established as a continuous gage
		02014000_RF3	*No*	*9/8/1965*	*6/7/1972*	*82*	*0.9385*	*0.9336*	*0.9094*	Moved gage
		02014000_RF4	*No*	*6/21/1972*	*10/8/1985*	*122*	*0.8990*	*0.9305*	*0.8929*	*Control changed by June 1972 flood from Hurricane Agnes*
		02014000_RF5	No	11/14/1985	1/6/1995	62	0.8796	0.9071	0.8835	Control changed by November 1985 flood
		02014000_RF6	Yes	2/16/1995	10/31/2013	152	0.9506	0.9587	0.9430	Control changed by January 1996 flood
02015700	Bullpasture River at Williamsville, VA	*02015700_RF1*	*No*	*8/2/1960*	*6/10/1974*	*171*	*0.8200*	*0.4591*	*0.8097*	*First RatFam at site*
		02015700_RF2	*No*	*7/12/1974*	*5/22/1979*	*50*	*0.9810*	*0.1971*	*0.7949*	*Moved gage*
		02015700_RF3	*No*	*7/12/1979*	*1/14/1985*	*50*	*0.9948*	*0.9917*	*0.9870*	*Graphical appearance*
		02015700_RF4	Yes	11/22/1985	9/3/2013	199	0.9844	0.9889	0.9861	Control changed by November 1985 flood
02016000	Cowpasture River near Clifton Forge, VA	02016000_RF1	Yes	3/26/1925	10/30/2013	663	0.9610	0.9659	0.9616	First RatFam at site
02016500	James River at Lick Run, VA	02016500_RF1	Yes	4/4/1925	10/29/2013	617	0.9937	0.9947	0.9937	First RatFam at site

Table 9   65

Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

[GAM, generalized additive model; R², coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; Italicized text represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R² of GAM of gage height as a function of flow	R² of GAM of flow as a function of gage height	Explanation
02017500	Johns Creek at New Castle, VA	02017500_RF1	Yes	12/29/1926	9/10/2013	200	0.9846	0.9866	0.9801	First RatFam at site
02018000	Craig Creek at Parr, VA	02018000_RF1	Yes	4/5/1925	10/30/2013	716	0.9901	0.9926	0.9878	First RatFam at site
02018500	Catawba Creek near Catawba, VA	*02018500_RF1*	*No*	*9/13/1943*	*7/8/1953*	*121*	*0.9908*	*0.9861*	*0.9885*	*First RatFam at site*
		02018500_RF2	*No*	*7/31/1953*	*3/29/1982*	*257*	*0.9606*	*0.9638*	*0.9500*	*Moved gage*
		02018500_RF3	No	11/4/1985	8/2/1994	45	0.9300	0.9640	0.9434	Data gap
		02018500_RF4	Yes	10/4/1994	10/22/2013	138	0.8344	0.9585	0.9050	Graphical appearance
02019500	James River at Buchanan, VA	02019500_RF1	Yes	3/30/1900	10/29/2013	708	0.9924	0.9900	0.9895	First RatFam at site
02020500	Calfpasture River above Mill Creek at Goshen, VA	*02020500_RF1*	*No*	*1/30/1939*	*5/3/1965*	*296*	*0.9717*	*0.9716*	*0.9537*	*First RatFam at site*
		02020500_RF2	No	11/21/1988	10/8/1996	70	0.9429	0.9610	0.9202	Concrete control damaged in floods while gage was discontinued
		02020500_RF3	No	10/25/1996	8/23/1999	27	0.3516	0.5186	0.5445	Last parts of the control were removed by landowner
		02020500_RF4	Yes	10/5/1999	9/3/2013	101	0.9978	0.9970	0.9954	Graphical appearance, but graphical app-earance of sta-bilization following control removal and 1996 floods
02021500	Maury River at Rockbridge Baths, VA	02021500_RF1	Yes	12/18/1928	10/29/2013	659	0.9960	0.9946	0.9936	First RatFam at site
02022500	Kerrs Creek near Lexington, VA	02022500_RF1	No	11/22/1988	12/5/1997	71	0.9897	0.9983	0.9967	First RatFam at site
		02022500_RF2	Yes	2/11/1998	8/22/2013	115	0.9049	0.9398	0.8923	Graphical appearance
02024000	Maury River near Buena Vista, VA	*02024000_RF1*	*No*	*3/14/1939*	*8/14/1969*	*299*	*0.9981*	*0.9978*	*0.9972*	*First RatFam at site*
		02024000_RF2	Yes	9/15/1969	10/29/2013	302	0.9813	0.9813	0.9739	Control changed by 1969 flood
02024752	James River at Blue Ridge Pkwy near Big Island, VA	02024752_RF1	Yes	6/8/2005	11/4/2013	51	0.9882	0.9971	0.9928	First RatFam at site
02024915	Pedlar River at Forest Road near Buena Vista, VA	02024915_RF1	Yes	11/6/2002	9/17/2013	75	0.9911	0.9946	0.9897	First RatFam at site
02025500	James River at Holcomb Rock, VA	02025500_RF1	Yes	9/20/1931	9/25/2013	438	0.9931	0.9949	0.9919	First RatFam at site
02026000	James River at Bent Creek, VA	02026000_RF1	Yes	3/21/1925	9/26/2013	449	0.9903	0.9925	0.9883	First RatFam at site
02027000	Tye River near Lovingston, VA	*02027000_RF1*	*No*	*7/12/1938*	*6/16/1944*	*62*	*0.8571*	*0.9482*	*0.8469*	*First RatFam at site*
		02027000_RF2	No	7/4/1944	9/5/1996	69	0.8962	0.9082	0.8049	Graphical appearance
		02027000_RF3	No	10/18/1996	7/22/2004	67	0.9958	0.9977	0.9945	Control changed by September 1996 flood
		02027000_RF4	Yes	9/3/2004	9/23/2013	60	0.9976	0.9972	0.9915	Graphical appearance, but coincided with datum change
02027500	Piney River at Piney River, VA	02027500_RF1	No	9/29/1988	9/6/2000	91	0.9902	0.9826	0.9720	First RatFam at site
		02027500_RF2	Yes	10/12/2000	9/23/2013	89	0.9775	0.9624	0.9205	Graphical appearance, but coincided with datum change
02028500	Rockfish River near Greenfield, VA	02028500_RF1	No	10/16/1942	10/9/2009	161	0.9896	0.9944	0.9816	First RatFam at site
		02028500_RF2	Yes	12/8/2009	9/23/2013	25	0.9935	0.9886	0.9765	Graphical appearance, but coincided with datum change
02029000	James River at Scottsville, VA	02029000_RF1	Yes	2/24/1925	10/24/2013	573	0.9915	0.9902	0.9887	First RatFam at site
02030000	Hardware River below Briery Run near Scottsville, VA	02030000_RF1	Yes	8/20/1969	10/16/2013	182	0.9837	0.9928	0.9812	First RatFam at site
02030500	Slate River near Arvonia, VA	*02030500_RF1*	*No*	*4/7/1926*	*6/22/1972*	*417*	*0.9930*	*0.9941*	*0.9935*	*First RatFam at site*
		02030500_RF2	Yes	6/28/1972	10/16/2013	339	0.9935	0.9950	0.9935	Control changed by June 1972 flood from Hurricane Agnes
02031000	Mechums River near White Hall, VA	02031000_RF1	Yes	4/17/1979	10/29/2013	240	0.9698	0.9834	0.9498	First RatFam at site
02032250	Moormans River near Free Union, VA	02032250_RF1	Yes	4/9/1980	10/29/2013	148	0.9676	0.9833	0.9569	First RatFam at site
02032640	North Fork Rivanna River near Earlysville, VA	02032640_RF1	Yes	10/4/1993	10/29/2013	169	0.9544	0.9543	0.9284	First RatFam at site
02034000	Rivanna River at Palmyra, VA	02034000_RF1	Yes	3/26/1937	10/16/2013	172	0.9919	0.9961	0.9949	First RatFam at site
02035000	James River at Cartersville, VA	02035000_RF1	Yes	4/2/1900	10/24/2013	793	0.9925	0.9832	0.9870	First RatFam at site
02036500	Fine Creek at Fine Creek Mills, VA	02036500_RF1	Yes	12/29/1958	9/10/2013	186	0.9702	0.9873	0.9324	First RatFam at site
02037000	James River And Kanawha Canal near Richmond, VA	02037000_RF1	Yes	10/23/1961	9/17/2013	213	0.3796	0.4690	0.4728	First RatFam at site
02037500	James River near Richmond, VA	02037500_RF1	Yes	8/24/1988	11/5/2013	135	0.9961	0.9930	0.9923	First RatFam at site
02038850	Holiday Creek near Andersonville, VA	02038850_RF1	Yes	5/2/1966	9/26/2013	401	0.9379	0.9644	0.9413	First RatFam at site
02039000	Buffalo Creek near Hampden Sydney, VA	*02039000_RF1*	*No*	*8/21/1946*	*7/6/1956*	*122*	*0.9669*	*0.9803*	*0.9793*	*First RatFam at site*
		02039000_RF2	*No*	*8/9/1956*	*12/6/1978*	*277*	*0.9170*	*0.9167*	*0.9181*	*Graphical appearance*
		02039000_RF3	Yes	9/19/1988	9/12/2013	178	0.8797	0.8812	0.8259	Data gap/hiatus
02039500	Appomattox River at Farmville, VA	02039500_RF1	Yes	3/25/1926	9/26/2013	720	0.9802	0.9864	0.9520	First RatFam at site

Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

[GAM, generalized additive model; R², coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; *Italicized text* represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R² of GAM of gage height as a function of flow	R² of GAM of flow as a function of gage height	Explanation
02040000	Appomattox River at Mattoax, VA	*02040000_RF1*	*No*	*8/25/1900*	*9/6/1905*	*28*	*0.9845*	*0.9882*	*0.9925*	*First RatFam at site*
		02040000_RF2	*No*	*3/27/1926*	*10/6/1958*	*241*	*0.9905*	*0.9928*	*0.9871*	*Established as a continuous gage*
		02040000_RF3	Yes	9/15/1988	9/10/2013	175	0.9791	0.9799	0.9604	Data gap
02040892	Appomattox River at Route 602 near Mannboro, VA	02040892_RF1	Yes	6/22/2011	10/23/2013	31	0.9972	0.9985	0.9984	First RatFam at site
02041000	Deep Creek near Mannboro, VA	02041000_RF1	Yes	9/6/1979	9/10/2013	188	0.9789	0.9579	0.9103	First RatFam at site
02041650	Appomattox River at Matoaca, VA	02041650_RF1	Yes	10/30/1969	9/11/2013	375	0.9956	0.9939	0.9926	First RatFam at site
02042500	Chickahominy River near Providence Forge, VA	02042500_RF1	Yes	11/7/1941	10/23/2013	647	0.9896	0.9798	0.9216	First RatFam at site
02044500	Nottoway River near Rawlings, VA	02044500_RF1	Yes	10/24/1971	9/11/2013	254	0.9928	0.9955	0.9842	First RatFam at site
02045500	Nottoway River near Stony Creek, VA	02045500_RF1	Yes	3/21/1930	9/11/2013	760	0.9838	0.9677	0.9552	First RatFam at site
02046000	Stony Creek near Dinwiddie, VA	02046000_RF1	Yes	10/6/1972	9/10/2013	256	0.9662	0.9661	0.9110	First RatFam at site
02047000	Nottoway River near Sebrell, VA	02047000_RF1	Yes	9/24/1941	11/7/2013	649	0.9969	0.9939	0.9904	First RatFam at site
02047500	Blackwater River near Dendron, VA	*02047500_RF1*	*No*	*1/8/1942*	*7/13/1976*	*365*	*0.9912*	*0.9839*	*0.9805*	*First RatFam at site*
		02047500_RF2	Yes	10/6/1976	10/17/2012	225	0.9836	0.9518	0.9239	Graphical appearance
02049500	Blackwater River near Franklin, VA	*02049500_RF1*	*No*	*8/24/1944*	*8/14/1973*	*289*	*0.9953*	*0.9911*	*0.9885*	*First RatFam at site*
		02049500_RF2	Yes	10/3/1973	11/4/2013	284	0.9847	0.9629	0.9061	Graphical appearance
02051000	North Meherrin River near Lunenburg, VA	02051000_RF1	Yes	10/8/1980	9/12/2013	240	0.9319	0.9401	0.9173	First RatFam at site
02051500	Meherrin River near Lawrenceville, VA	02051500_RF1	Yes	12/19/1928	11/6/2013	653	0.9941	0.9931	0.9888	First RatFam at site
02052000	Meherrin River at Emporia, VA	02052000_RF1	Yes	10/9/1980	9/11/2013	245	0.9856	0.9772	0.9472	First RatFam at site
02053800	South Fork Roanoke River near Shawsville, VA	*02053800_RF1*	*No*	*10/5/1980*	*10/1/1985*	*43*	*0.9894*	*0.9928*	*0.9916*	*First RatFam at site*
		02053800_RF2	*No*	*6/18/1986*	*9/27/1988*	*20*	*0.6938*	*0.8168*	*0.9163*	*Control changed by November 1985 flood*
		02053800_RF3	*No*	*11/21/1988*	*8/20/1996*	*59*	*0.9667*	*0.9545*	*0.9622*	*Graphical appearance*
		02053800_RF4	No	1/8/1998	8/24/2004	54	0.9895	0.9906	0.9899	Data gap
		02053800_RF5	Yes	9/8/2004	10/22/2013	62	0.9062	0.8783	0.9021	Graphical appearance
02054500	Roanoke River at Lafayette, VA	02054500_RF1	Yes	7/4/1948	10/22/2013	248	0.8797	0.9221	0.8966	First RatFam at site
02054530	Roanoke River at Glenvar, VA	02054530_RF1	Yes	10/16/1991	10/22/2013	162	0.9974	0.9980	0.9976	First RatFam at site
02055000	Roanoke River near Roanoke, VA	02055000_RF1	Yes	3/19/1900	10/29/2013	783	0.9809	0.9734	0.9787	First RatFam at site
02055100	Tinker Creek near Daleville, VA	02055100_RF1	Yes	4/27/1956	10/29/2013	490	0.8608	0.9241	0.8496	First RatFam at site
02056000	Roanoke River at Niagara, VA	02056000_RF1	Yes	7/11/1926	10/29/2013	588	0.9927	0.9858	0.9868	First RatFam at site
02056650	Back Creek near Dundee, VA	*02056650_RF1*	*No*	*8/15/1974*	*10/21/1985*	*95*	*0.9910*	*0.9833*	*0.9899*	*First RatFam at site*
		02056650_RF2	Yes	11/25/1985	10/21/2013	215	0.9885	0.9881	0.9718	Control changed by November 1985 flood
02056900	Blackwater River near Rocky Mount, VA	02056900_RF1	Yes	10/26/1976	10/21/2013	275	0.9938	0.9916	0.9792	First RatFam at site
02058400	Pigg River near Sandy Level, VA	02058400_RF1	Yes	5/8/1962	9/10/2013	382	0.9862	0.9939	0.9857	First RatFam at site
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	02059485_RF1	Yes	12/12/2006	9/25/2013	54	0.9820	0.9862	0.9791	First RatFam at site
02059500	Goose Creek near Huddleston, VA	02059500_RF1	Yes	10/6/1980	10/21/2013	254	0.9717	0.9265	0.9470	First RatFam at site
02060500	Roanoke River at Altavista, VA	*02060500_RF1*	*No*	*7/15/1930*	*4/15/1969*	*343*	*0.9850*	*0.9844*	*0.9731*	*First RatFam at site*
		02060500_RF2	*No*	*6/4/1969*	*8/25/1988*	*138*	*0.9508*	*0.9849*	*0.9803*	*Graphical appearance*
		02060500_RF3	Yes	8/6/1990	11/5/2013	162	0.9668	0.9912	0.9892	Data gap/hiatus
02061000	Big Otter River near Bedford, VA	02061000_RF1	Yes	12/12/2006	9/25/2013	57	0.9770	0.9720	0.9152	First RatFam at site
02061500	Big Otter River near Evington, VA	*02061500_RF1*	*No*	*11/3/1936*	*10/1/1973*	*326*	*0.9930*	*0.9944*	*0.9916*	*First RatFam at site*
		02061500_RF2	*No*	*5/14/1975*	*5/23/2005*	*236*	*0.9472*	*0.9610*	*0.9465*	*Bridge construction*
		02061500_RF3	Yes	7/25/2005	10/21/2013	58	0.9900	0.9905	0.9839	Graphical appearance but coincided with datum change
02062500	Roanoke (Staunton) River at Brookneal, VA	*02062500_RF1*	*No*	*4/29/1923*	*6/5/1941*	*89*	*0.9836*	*0.9884*	*0.9863*	*First RatFam at site*
		02062500_RF2	Yes	7/17/1941	11/4/2013	547	0.9649	0.9721	0.9542	Moved gage
02064000	Falling River near Naruna, VA	02064000_RF1	Yes	7/12/1929	9/12/2013	643	0.9754	0.9924	0.9751	First RatFam at site
02065500	Cub Creek at Phenix, VA	02065500_RF1	Yes	7/6/1972	9/12/2013	242	0.9607	0.9761	0.9455	First RatFam at site
02066000	Roanoke (Staunton) River at Randolph, VA	02066000_RF1	Yes	4/17/1930	9/9/2013	506	0.9818	0.9874	0.9813	First RatFam at site
02069700	South Mayo River near Nettleridge, VA	02069700_RF1	Yes	6/21/1972	10/23/2013	235	0.9847	0.9930	0.9860	First RatFam at site
02070000	North Mayo River near Spencer, VA	02070000_RF1	Yes	4/20/1939	10/23/2013	237	0.9941	0.9960	0.9947	First RatFam at site

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Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

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Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R² of GAM of gage height as a function of flow	R² of GAM of flow as a function of gage height	Explanation
02071530	Smith River at Smith Riv Church near Woolwine, VA	02071530_RF1	No	8/17/1994	10/5/2005	92	0.9217	0.9566	0.9250	First RatFam at site
		02071530_RF2	Yes	12/14/2005	10/23/2013	51	0.9844	0.9703	0.9712	Graphical appearance
02072000	Smith River near Philpott, VA	*02072000_RF1*	*No*	*9/18/1946*	*10/11/1952*	*85*	*0.9929*	*0.9987*	*0.9977*	*First RatFam at site*
		02072000_RF2	Yes	11/19/1952	9/11/2013	419	0.9623	0.9965	0.9918	Moved gage
02072500	Smith River at Bassett, VA	*02072500_RF1*	*No*	*4/21/1939*	*4/10/1956*	*179*	*0.9879*	*0.9944*	*0.9701*	*First RatFam at site*
		02072500_RF2	Yes	7/24/1956	11/6/2013	459	0.9331	0.9900	0.9857	Graphical appearance
02073000	Smith River at Martinsville, VA	02073000_RF1	Yes	10/19/1937	9/11/2013	193	0.9816	0.9913	0.9870	First RatFam at site
02074500	Sandy River near Danville, VA	02074500_RF1	Yes	9/28/1983	9/11/2013	176	0.9854	0.9893	0.9849	First RatFam at site
02075045	Dan River at Stp near Danville, VA	02075045_RF1	Yes	10/28/1993	11/5/2013	145	0.9860	0.9953	0.9917	First RatFam at site
02075500	Dan River at Paces, VA	*02075500_RF1*	*No*	*11/10/1950*	*12/4/1971*	*205*	*0.9944*	*0.9953*	*0.9946*	*First RatFam at site*
		02075500_RF2	Yes	2/1/1972	11/6/2013	277	0.9907	0.9886	0.9884	Graphical appearance
02077000	Banister River at Halifax, VA	*02077000_RF1*	*No*	*1/25/1929*	*3/20/1946*	*122*	*0.9722*	*0.9724*	*0.9724*	*First RatFam at site*
		02077000_RF2	*No*	*6/6/1946*	*9/6/1950*	*51*	*0.8436*	*0.9198*	*0.9897*	*Graphical appearance*
		02077000_RF3	*No*	*10/6/1950*	*8/25/1970*	*183*	*0.9740*	*0.7193*	*0.9458*	*Moved gage*
		02077000_RF4	*No*	*12/3/1981*	*8/14/2002*	*85*	*0.8665*	*0.9746*	*0.9435*	*Data gap*
		02077000_RF6	Yes	7/7/2005	11/7/2013	50	0.9854	0.9973	0.9935	Graphical appearance, but followed a datum change
02077500	Hyco River near Denniston, VA	*02077500_RF1*	*No*	*7/11/1929*	*12/3/1981*	*317*	*0.9827*	*0.9869*	*0.9466*	*First RatFam at site*
		02077500_RF2	No	3/10/1982	1/22/2003	147	0.9780	0.9846	0.9536	Graphical appearance
		02077500_RF3	Yes	3/12/2003	9/12/2013	66	0.9576	0.9817	0.9705	Graphical appearance
02079640	Allen Creek near Boydton, VA	02079640_RF1	No	9/22/1961	10/21/1996	353	0.9502	0.9631	0.9340	First RatFam at site
		02079640_RF2	Yes	9/7/2000	8/22/2013	107	0.7852	0.8382	0.6796	Data gap/hiatus
03164000	New River near Galax, VA	03164000_RF1	Yes	11/24/1929	10/18/2013	636	0.9873	0.9856	0.9847	First RatFam at site
03165000	Chestnut Creek at Galax, VA	*03165000_RF1*	*No*	*8/14/1940*	*5/6/1948*	*49*	*0.9851*	*0.9953*	*0.9938*	*First RatFam at site*
		03165000_RF2	*No*	*7/8/1948*	*1/9/1951*	*31*	*0.9812*	*0.9981*	*0.9975*	*Established as a continuous gage*
		03165000_RF3	*No*	*2/27/1951*	*5/11/1953*	*27*	*0.9714*	*0.9682*	*0.9611*	*Graphical appearance*
		03165000_RF4	*No*	*6/8/1953*	*10/10/1968*	*157*	*0.9084*	*0.9019*	*0.8735*	*Moved gage*
		03165000_RF5	*No*	*11/21/1968*	*10/17/1975*	*60*	*0.9441*	*0.9178*	*0.8293*	*Graphical appearance*
		03165000_RF6	*No*	*11/26/1975*	*7/23/1979*	*27*	*0.9056*	*0.8663*	*0.9420*	*Graphical appearance*
		03165000_RF7	Yes	8/31/1979	10/18/2013	288	0.9744	0.3989	0.9660	Concrete control built
03165500	New River at Ivanhoe, VA	03165500_RF1	Yes	10/2/1927	10/21/2013	497	0.9886	0.9890	0.9882	First RatFam at site
03167000	Reed Creek at Grahams Forge, VA	03167000_RF1	Yes	2/3/1927	10/28/2013	712	0.9947	0.9909	0.9926	First RatFam at site
03168000	New River at Allisonia, VA	03168000_RF1	Yes	1/7/1930	10/21/2013	630	0.9926	0.9889	0.9899	First RatFam at site
03170000	Little River at Graysontown, VA	*03170000_RF1*	*No*	*10/30/1928*	*11/20/1931*	*28*	*0.9800*	*0.9929*	*0.9720*	*First RatFam at site*
		03170000_RF2	*No*	*1/16/1932*	*7/15/1940*	*46*	*0.9672*	*0.9667*	*0.9723*	*Moved gage*
		03170000_RF4	Yes	9/15/1942	10/24/2013	646	0.9790	0.9799	0.9769	Moved gage
03171000	New River at Radford, VA	03171000_RF1	Yes	7/12/1939	10/24/2013	452	0.9947	0.9952	0.9932	First RatFam at site
03173000	Walker Creek at Bane, VA	03173000_RF1	Yes	3/31/1938	10/28/2013	668	0.9979	0.9971	0.9966	First RatFam at site
03175500	Wolf Creek near Narrows, VA	03175500_RF1	Yes	6/8/1909	10/21/2013	676	0.9615	0.9648	0.9429	First RatFam at site
03176500	New River at Glen Lyn, VA	*03176500_RF1*	*No*	*9/2/1927*	*1/10/1957*	*220*	*0.9972*	*0.9971*	*0.9964*	*First RatFam at site*
		03176500_RF2	*No*	*3/5/1957*	*4/17/1987*	*264*	*0.9678*	*0.9522*	*0.9486*	*Graphical appearance*
		03176500_RF3	Yes	5/13/1987	10/22/2013	206	0.9963	0.9405	0.9361	Graphical appearance
03177710	Bluestone River at Falls Mills, VA	03177710_RF1	Yes	9/25/1980	10/22/2013	237	0.9553	0.9786	0.9440	First RatFam at site
03207800	Levisa Fork at Big Rock, VA	*03207800_RF1*	*No*	*9/18/1967*	*2/13/1989*	*204*	*0.9032*	*0.9102*	*0.8463*	*First RatFam at site*
		03207800_RF2	Yes	4/10/1989	10/28/2013	193	0.9807	0.9727	0.9674	Graphical appearance
03208500	Russell Fork at Haysi, VA	*03208500_RF1*	*No*	*7/19/1926*	*12/20/1939*	*45*	*0.9984*	*0.9984*	*0.9976*	*First RatFam at site*
		03208500_RF2	Yes	3/6/1940	10/23/2013	715	0.9863	0.9850	0.9771	Moved gage and changed datum
03208950	Cranes Nest River near Clintwood, VA	03208950_RF1	No	9/27/1963	5/31/2007	393	0.9633	0.9636	0.9435	First RatFam at site

Table 9. Rating families, dates they were in effect, variability statistics, and explanations for their causes for streamgages active in Virginia in October 2013.—Continued

[GAM, generalized additive model; R^2, coefficient of determination; RatFam, rating family; VA, Virginia; Rt, Route; *Italicized text* represents rating families that ended before the primary study period, water years 1991–2013]

Streamgage number	Streamgage name	Rating family	Used in multisite analysis?	First measurement	Final or most recent measurement	Number of measurements	Spearman's rho	R^2 of GAM of gage height as a function of flow	R^2 of GAM of flow as a function of gage height	Explanation
03209000	Pound River below Flannagan Dam, near Haysi, VA	03209000_RF2	Yes	7/16/2007	10/23/2013	52	0.8062	0.8578	0.8511	Graphical appearance
		03209000_RF1	Yes	12/4/1961	10/23/2013	422	0.9898	0.9968	0.9940	First RatFam at site
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	*03471500_RF1*	*No*	*3/20/1909*	*12/28/1931*	*40*	*0.9039*	*0.7900*	*0.8869*	*First RatFam at site*
		03471500_RF2	*No*	*7/17/1942*	*12/5/1956*	*174*	*0.9966*	*0.9976*	*0.9967*	*Data gap*
		03471500_RF3	*No*	*1/9/1957*	*11/6/1977*	*237*	*0.9948*	*0.9944*	*0.9930*	*Graphical appearance*
		03471500_RF4	*No*	*11/18/1977*	*8/18/1989*	*96*	*0.9879*	*0.9912*	*0.9864*	*Control changed by flood*
		03471500_RF5	Yes	10/6/1989	10/18/2013	200	0.9869	0.9837	0.9827	Graphical appearance
03473000	South Fork Holston River near Damascus, VA	*03473000_RF1*	*No*	*11/12/1931*	*7/26/1951*	*191*	*0.9979*	*0.9976*	*0.9967*	*First RatFam at site*
		03473000_RF2	No	8/14/1951	10/20/2003	478	0.9732	0.9710	0.9637	Bridge construction noted on measurement form
		03473000_RF3	Yes	12/12/2003	10/17/2013	71	0.9943	0.9886	0.9865	Control change believed due to a piece of construction equipment breaking a piece of rock off a ledge and leaving it on the control.
03474000	Middle Fork Holston River at Seven Mile Ford, VA	*03474000_RF1*	*No*	*7/17/1942*	*9/8/1953*	*144*	*0.9828*	*0.9908*	*0.9829*	*First RatFam at site*
		03474000_RF2	*No*	*9/14/1953*	*2/2/1961*	*94*	*0.9785*	*0.9952*	*0.9849*	*Concrete control built*
		03474000_RF3	*No*	*3/2/1961*	*9/11/1962*	*28*	*0.6383*	*0.6268*	*0.4927*	*Graphical appearance*
		03474000_RF4	Yes	11/7/1962	10/18/2013	355	0.9949	0.9960	0.9954	New concrete control built
03475000	Middle Fork Holston River near Meadowview, VA	03475000_RF1	Yes	11/6/1931	10/29/2013	529	0.9907	0.9919	0.9882	First RatFam at site
03478400	Beaver Creek at Bristol, VA	*03478400_RF1*	*No*	*7/11/1957*	*4/6/1972*	*185*	*0.9695*	*0.9751*	*0.9587*	*First RatFam at site*
		03478400_RF2	No	5/2/1972	11/4/2008	307	0.9665	0.9699	0.9514	Graphical appearance; approximate time that Interstate 81 bridge was built, and subsequent measurement forms discuss fill downstream
		03478400_RF3	No	1/6/2009	2/28/2012	36	0.9889	0.9845	0.9920	New control from stream restoration project
		03478400_RF4	Yes	4/5/2012	10/29/2013	24	0.9821	0.9977	0.9855	Bridge construction
03488000	North Fork Holston River near Saltville, VA	*03488000_RF1*	*No*	*11/2/1920*	*4/11/1934*	*47*	*0.9630*	*0.9515*	*0.9516*	*First RatFam at site*
		03488000_RF2	Yes	6/16/1934	10/18/2013	871	0.9864	0.9772	0.9781	Moved gage and changed datum.
03490000	North Fork Holston River near Gate City, VA	03490000_RF1	Yes	10/18/1931	10/17/2013	557	0.9939	0.9934	0.9912	First RatFam at site
03524000	Clinch River at Cleveland, VA	*03524000_RF1*	*No*	*10/9/1920*	*4/24/1931*	*40*	*0.9932*	*0.9941*	*0.9925*	*First RatFam at site*
		03524000_RF2	Yes	11/9/1931	10/22/2013	706	0.9932	0.9909	0.9892	Moved gage and changed datum.
03524500	Guest River at Coeburn, VA	03524500_RF1	Yes	6/7/1949	10/22/2013	185	0.9759	0.9861	0.9651	First RatFam at site
03527000	Clinch River at Speers Ferry, VA	03527000_RF1	Yes	1/4/1927	10/17/2013	641	0.9920	0.9892	0.9874	First RatFam at site
03529500	Powell River at Big Stone Gap, VA	*03529500_RF1*	*No*	*10/27/1944*	*4/5/1977*	*180*	*0.9939*	*0.9929*	*0.9876*	*First RatFam at site*
		03529500_RF2	*No*	*4/5/1978*	*10/5/1981*	*34*	*0.9357*	*0.9709*	*0.9594*	*Data gap/hiatus*
		03529500_RF3	Yes	9/19/2001	10/21/2013	112	0.9496	0.7520	0.7925	Data gap/hiatus
03531500	Powell River near Jonesville, VA	03531500_RF1	Yes	11/8/1931	10/21/2013	800	0.9928	0.9904	0.9880	First RatFam at site

Table 13   69

Table 13. Number of days with estimated and qualified flows for streamgages in Virginia, water years 1991–2013.

[A:e, National Water Information System (NWIS) remark code indicating that a daily flow value was estimated; A:1, NWIS remark code indicating that a daily flow value was write-protected without a remark code; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Estimated (A:e) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage estimated overall	Percentage estimated during winter	Write-protected (A:1) Total	Total daily values
01613900	Hogue Creek near Hayfield, VA	105	69	8	2	3	0	2	5	8	35	23	37	297	0.07	0.19	20	4,381
01615000	Opequon Creek near Berryville, VA	128	65	0	1	1	0	2	2	30	52	44	52	377	0.06	0.15	17	6,585
01616100	Dry Marsh Run near Berryville, VA	39	33	31	34	40	51	27	33	32	42	33	33	428	0.11	0.10	27	4,057
01620500	North River near Stokesville, VA	42	57	15	2	14	13	18	9	15	35	26	6	252	0.06	0.10	46	4,410
01621050	Muddy Creek at Mount Clinton, VA	72	41	21	26	9	2	16	0	26	10	11	62	296	0.05	0.12	37	6,138
01622000	North River near Burketown, VA	17	3	6	0	0	10	5	5	24	4	0	1	75	0.02	0.02	5	4,442
01625000	Middle River near Grottoes, VA	128	45	5	0	0	0	4	0	14	42	30	41	309	0.04	0.10	5	8,400
01626000	South River near Waynesboro, VA	55	27	7	13	12	0	4	0	21	26	4	10	179	0.02	0.04	9	8,400
01626850	South River near Dooms, VA	22	13	0	1	1	0	4	0	24	6	16	4	91	0.02	0.03	4	5,256
01627500	South River at Harriston, VA	23	8	2	0	1	0	0	0	6	1	5	7	53	0.01	0.03	8	4,681
01628500	South Fork Shenandoah River near Lynnwood, VA	51	43	0	0	0	5	0	0	1	0	0	5	105	0.01	0.05	12	8,400
01629500	South Fork Shenandoah River near Luray, VA	21	9	15	24	16	15	34	6	25	1	2	0	168	0.04	0.03	23	4,443
01631000	South Fork Shenandoah River at Front Royal, VA	63	14	3	0	8	7	21	15	4	3	7	14	159	0.04	0.08	50	4,428
01632000	North Fork Shenandoah River at Cootes Store, VA	93	50	8	0	12	7	58	113	85	69	40	24	559	0.09	0.11	56	6,046
01632082	Linville Creek at Broadway, VA	130	49	12	1	11	15	1	26	70	49	60	46	470	0.06	0.11	16	8,399
01632900	Smith Creek near New Market, VA	160	66	1	2	2	11	6	40	52	58	39	57	494	0.06	0.14	11	8,399
01633000	North Fork Shenandoah River at Mount Jackson, VA	38	13	0	0	1	0	0	0	0	8	5	3	68	0.01	0.05	10	4,577
01634000	North Fork Shenandoah River near Strasburg, VA	112	44	0	0	0	8	32	14	2	13	2	20	247	0.04	0.11	96	6,207
01634500	Cedar Creek near Winchester, VA	234	106	23	10	26	26	26	18	20	74	54	71	688	0.08	0.20	14	8,392
01635500	Passage Creek near Buckton, VA	249	163	8	1	24	4	0	5	0	6	4	77	541	0.06	0.24	6	8,390
01636316	Spout Run at Rt 621 near Millwood, VA	33	32	31	21	37	33	12	4	16	52	30	34	335	0.08	0.10	43	4,044
01636690	Piney Run near Lovettsville, VA	68	70	39	11	3	0	0	0	0	0	0	20	211	0.05	0.15	9	4,368
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	82	42	2	0	4	0	17	21	4	0	0	19	191	0.04	0.13	41	4,443
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	73	36	5	0	0	0	5	2	19	6	1	31	178	0.04	0.13	31	4,443
01638480	Catoctin Creek at Taylorstown, VA	88	65	26	12	21	27	6	11	7	29	6	28	326	0.07	0.17	23	4,382
01643590	Limestone Branch near Leesburg, VA	16	8	0	0	2	1	1	0	0	0	12	10	49	0.01	0.03	32	4,408
01643700	Goose Creek near Middleburg, VA	63	73	11	2	2	10	18	11	8	1	8	35	242	0.05	0.16	49	4,442
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	111	78	37	58	43	51	41	54	47	31	36	48	635	0.14	0.22	10	4,408
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	37	39	2	0	0	0	3	24	14	3	0	38	160	0.04	0.10	38	4,443
01644000	Goose Creek near Leesburg, VA	80	55	1	1	15	10	2	10	47	25	13	12	271	0.06	0.13	11	4,634
01644280	Broad Run near Leesburg, VA	32	30	6	0	1	27	10	13	0	18	21	32	190	0.04	0.09	28	4,240
01645704	Difficult Run above Fox Lake near Fairfax, VA	0	0	0	0	5	31	13	3	2	4	13	1	72	0.03	0.00	9	2,196
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	5	1	0	9	10	7	8	1	0	21	23	7	92	0.04	0.02	36	2,196
01646000	Difficult Run near Great Falls, VA	165	82	8	6	4	2	2	9	17	105	78	57	535	0.06	0.15	10	8,393
01646305	Dead Run at Whann Avenue near Mclean, VA	2	3	0	0	1	10	5	0	0	0	0	0	22	0.01	0.01	10	2,050
01652500	Fourmile Run at Alexandria, VA	58	71	34	16	15	7	25	7	23	11	27	26	320	0.06	0.11	62	5,473
01653000	Cameron Run at Alexandria, VA	64	27	29	56	19	35	1	2	12	20	1	10	276	0.04	0.07	11	6,208
01654000	Accotink Creek near Annandale, VA	110	66	3	7	7	8	46	24	41	40	62	42	456	0.10	0.20	11	4,383
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	0	1	5	2	0	0	0	0	0	0	1	0	9	0.01	0.01	22	701
01656000	Cedar Run near Catlett, VA	170	121	44	18	26	2	6	4	33	3	12	63	502	0.06	0.17	18	8,393
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	0	2	0	0	0	12	23	27	24	6	1	1	96	0.04	0.01	8	2,196
01658500	South Fork Quantico Creek near Independent Hill, VA	34	12	3	1	0	7	30	37	6	58	10	14	212	0.03	0.04	34	6,181
01660400	Aquia Creek near Garrisonville, VA	112	49	18	0	29	30	86	96	57	19	14	79	589	0.12	0.19	13	5,068
01662800	Battle Run near Laurel Mills, VA	164	82	6	7	17	33	4	35	32	67	43	41	531	0.07	0.15	5	7,584
01663500	Hazel River at Rixeyville, VA	73	27	6	4	24	16	20	2	19	15	0	18	224	0.05	0.11	52	4,365

Table 13. Number of days with estimated and qualified flows for streamgages in Virginia, water years 1991–2013.—Continued

[A:e, National Water Information System (NWIS) remark code indicating that a daily flow value was estimated; A:1, NWIS remark code indicating that a daily flow value was write-protected without a remark code; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Estimated (A:e)															Write-protected (A:1)	
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage estimated overall	Percentage estimated during winter	Total	Total daily values
01664000	Rappahannock River at Remington, VA	39	7	2	2	4	0	20	34	10	3	0	10	131	0.03	0.05	28	4,381
01665500	Rapidan River near Ruckersville, VA	109	45	21	2	0	0	13	9	9	4	17	72	301	0.06	0.17	1	5,464
01666500	Robinson River near Locust Dale, VA	168	77	47	12	36	16	14	14	42	4	0	30	460	0.05	0.13	5	8,398
01667500	Rapidan River near Culpeper, VA	50	40	20	38	4	15	4	4	6	11	0	2	194	0.04	0.08	4	4,631
01668000	Rappahannock River near Fredericksburg, VA	69	12	3	0	0	12	15	1	4	6	5	38	165	0.03	0.10	32	4,725
01669000	Piscataway Creek near Tappahannock, VA	73	29	12	1	1	0	15	4	9	39	52	13	248	0.06	0.11	4	4,396
01669520	Dragon Swamp at Mascot, VA	59	19	4	0	2	0	2	27	2	11	6	8	140	0.03	0.08	2	4,562
01670400	North Anna River near Partlow, VA	0	0	0	0	0	3	11	11	3	30	30	0	88	0.02	0.00	9	4,198
01671020	North Anna River at Hart Corner near Doswell, VA	69	43	14	9	24	27	14	38	32	18	5	31	324	0.06	0.10	6	5,537
01671025	North Anna River above Little River near Doswell, VA	10	1	4	5	30	10	11	8	0	8	19	10	116	0.04	0.03	11	3,189
01671100	Little River near Doswell, VA	31	19	13	0	2	0	2	5	14	33	0	6	125	0.03	0.05	3	4,436
01672500	South Anna River near Ashland, VA	36	23	2	0	0	13	24	18	21	2	0	5	144	0.04	0.07	30	3,880
01673000	Pamunkey River near Hanover, VA	34	11	13	0	2	22	11	2	9	6	13	21	144	0.02	0.04	33	6,060
01673550	Totopotomoy Creek near Studley, VA	131	29	20	23	40	21	42	78	84	47	50	51	616	0.07	0.10	3	8,400
01673800	Po River near Spotsylvania, VA	84	45	0	29	34	9	15	26	102	136	101	29	610	0.07	0.08	7	8,393
01674000	Mattaponi River near Bowling Green, VA	91	47	0	7	0	4	22	10	40	122	122	56	521	0.06	0.09	8	8,392
01674500	Mattaponi River near Beulahville, VA	56	15	4	0	0	3	4	14	36	6	1	17	156	0.02	0.05	50	6,613
02011400	Jackson River near Bacova, VA	130	29	0	0	0	0	1	0	0	0	7	47	214	0.03	0.12	30	6,937
02011460	Back Creek near Sunrise, VA	73	15	0	0	0	0	0	0	0	0	3	10	101	0.02	0.09	15	4,465
02011470	Back Creek at Sunrise, VA	0	1	0	0	5	0	4	3	0	0	0	0	13	0.00	0.00	32	6,937
02011490	Little Back Creek near Sunrise, VA	35	20	2	3	3	1	1	0	1	0	0	6	72	0.02	0.06	88	4,017
02011500	Back Creek near Mountain Grove, VA	36	34	2	2	0	5	0	1	0	2	0	8	90	0.01	0.05	27	6,937
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	0	0	0	0	5	0	4	0	1	9	0	0	19	0.00	0.00	72	6,936
02013000	Dunlap Creek near Covington, VA	68	17	2	0	5	7	6	3	25	0	0	29	155	0.02	0.07	37	6,607
02013100	Jackson River below Dunlap Creek at Covington, VA	15	0	2	1	1	0	0	0	0	0	8	10	37	0.01	0.02	28	6,671
02014000	Potts Creek near Covington, VA	73	11	1	0	0	0	0	2	0	0	0	21	109	0.02	0.06	34	6,802
02015700	Bullpasture River at Williamsville, VA	107	80	30	1	2	0	11	0	3	1	30	49	314	0.06	0.17	5	5,502
02016000	Cowpasture River near Clifton Forge, VA	57	6	0	0	0	4	0	0	0	0	0	11	78	0.02	0.06	18	5,067
02016500	James River at Lick Run, VA	24	3	4	0	0	0	2	2	0	0	0	6	41	0.01	0.02	24	5,669
02017500	Johns Creek at New Castle, VA	52	30	3	1	7	5	13	5	5	3	4	21	149	0.03	0.10	14	4,382
02018000	Craig Creek at Parr, VA	29	4	0	0	0	2	11	3	5	2	0	4	60	0.01	0.03	67	4,383
02018500	Catawba Creek near Catawba, VA	40	12	1	1	2	6	0	0	7	16	24	12	115	0.03	0.06	4	4,382
02019500	James River at Buchanan, VA	18	2	4	4	6	6	0	0	0	0	0	5	45	0.01	0.02	21	5,621
02020500	Calfpasture River above Mill Creek at Goshen, VA	152	62	40	17	0	7	6	0	7	19	34	84	428	0.08	0.22	5	5,465
02021500	Maury River at Rockbridge Baths, VA	110	38	0	0	0	1	8	13	10	0	25	27	232	0.04	0.12	11	6,139
02022500	Kerrs Creek near Lexington, VA	41	14	3	0	2	0	0	11	4	5	6	14	100	0.02	0.06	21	4,569
02024000	Maury River near Buena Vista, VA	66	22	0	0	15	24	20	3	0	8	14	20	192	0.04	0.09	10	5,109
02024752	James River at Blue Ridge Pkwy near Big Island, VA	19	0	0	0	5	0	0	0	0	4	0	2	30	0.01	0.03	27	2,554
02024915	Pedlar River at Forest Road near Buena Vista, VA	79	24	2	0	1	0	10	9	18	4	8	29	184	0.05	0.13	85	3,975
02025500	James River at Holcomb Rock, VA	32	20	28	11	14	9	0	24	30	9	0	13	190	0.04	0.05	23	5,366
02026000	James River at Bent Creek, VA	2	0	5	4	7	11	1	0	3	18	7	1	59	0.01	0.00	81	4,367
02027000	Tye River near Lovingston, VA	109	22	50	2	16	32	26	54	21	46	25	89	492	0.09	0.16	23	5,467
02027500	Piney River at Piney River, VA	51	11	21	5	8	0	0	1	5	11	16	18	147	0.03	0.07	6	4,569
02028500	Rockfish River near Greenfield, VA	93	26	5	2	24	0	9	5	6	28	47	26	271	0.05	0.11	17	5,544
02029000	James River at Scottsville, VA	11	6	2	12	2	16	26	0	1	0	11	1	88	0.01	0.01	19	6,154

Table 13   71

Table 13. Number of days with estimated and qualified flows for streamgages in Virginia, water years 1991–2013.—Continued

[A:e, National Water Information System (NWIS) remark code indicating that a daily flow value was estimated; A:1, NWIS remark code indicating that a daily flow value was write-protected without a remark code; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Estimated (A:e) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage estimated overall	Percentage estimated during winter	Write-protected (A:1) Total	Total daily values
02030000	Hardware River below Briery Run near Scottsville, VA	102	23	3	8	14	8	17	3	7	18	4	41	248	0.04	0.11	10	5,842
02030500	Slate River near Arvonia, VA	42	13	1	30	0	0	0	2	0	0	0	18	106	0.02	0.06	7	4,834
02031000	Mechums River near White Hall, VA	72	19	7	2	9	3	10	10	0	40	15	21	208	0.05	0.10	6	4,369
02032250	Moormans River near Free Union, VA	47	28	43	15	70	20	6	4	0	32	64	42	371	0.12	0.16	5	3,008
02032640	North Fork Rivanna River near Earlysville, VA	153	55	41	23	17	9	58	47	47	30	17	37	534	0.07	0.14	4	7,302
02034000	Rivanna River at Palmyra, VA	33	3	1	2	1	1	0	8	19	6	2	2	78	0.02	0.03	8	4,521
02035000	James River at Cartersville, VA	12	34	15	32	8	58	61	35	18	4	6	7	290	0.03	0.03	31	8,372
02036500	Fine Creek at Fine Creek Mills, VA	101	18	0	6	11	55	37	59	79	65	30	32	493	0.06	0.07	4	8,393
02037000	James River And Kanawha Canal near Richmond, VA	0	0	1	1	0	3	1	0	0	0	0	0	6	0.00	0.00	17	4,569
02037500	James River near Richmond, VA	11	2	11	9	4	6	12	5	6	6	3	5	80	0.01	0.01	5	5,816
02038850	Holiday Creek near Andersonville, VA	82	72	31	47	0	0	0	7	40	54	15	29	377	0.08	0.17	45	4,481
02039000	Buffalo Creek near Hampden Sydney, VA	102	25	39	28	57	25	16	12	12	4	1	31	352	0.04	0.08	5	8,398
02039500	Appomattox River at Farmville, VA	41	18	2	10	19	0	3	14	5	0	0	4	116	0.03	0.06	37	4,575
02040000	Appomattox River at Mattoax, VA	177	53	4	14	37	65	65	66	81	61	109	107	839	0.10	0.16	9	8,393
02040892	Appomattox River at Route 602 near Mannboro, VA	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	3	815
02041000	Deep Creek near Mannboro, VA	80	18	2	2	12	2	0	6	20	20	30	31	221	0.03	0.06	2	8,393
02041650	Appomattox River at Matoaca, VA	25	0	0	0	7	0	0	1	4	11	0	8	56	0.01	0.03	4	4,845
02042500	Chickahominy River near Providence Forge, VA	42	9	2	0	8	0	0	2	4	1	0	8	76	0.01	0.04	14	6,094
02044500	Nottoway River near Rawlings, VA	22	7	5	6	14	10	8	12	5	4	0	0	93	0.02	0.03	6	4,478
02045500	Nottoway River near Stony Creek, VA	70	12	5	14	22	44	59	75	31	36	36	38	442	0.05	0.06	16	8,392
02046000	Stony Creek near Dinwiddie, VA	30	2	10	0	1	28	18	11	17	36	2	6	161	0.04	0.04	40	4,374
02047000	Nottoway River near Sebrell, VA	5	2	14	3	3	25	19	10	7	0	0	0	88	0.02	0.01	11	4,726
02047500	Blackwater River near Dendron, VA	32	24	16	0	2	4	3	1	6	6	12	20	126	0.02	0.04	7	8,398
02049500	Blackwater River near Franklin, VA	0	2	0	2	0	3	1	5	39	19	8	0	79	0.01	0.00	108	5,991
02051000	North Meherrin River near Lunenburg, VA	64	13	0	15	21	0	6	0	15	36	38	29	237	0.04	0.08	44	5,718
02051500	Meherrin River near Lawrenceville, VA	89	46	16	33	17	40	42	8	30	1	2	33	363	0.06	0.11	24	6,208
02052000	Meherrin River at Emporia, VA	8	0	0	0	13	0	27	2	0	2	0	16	68	0.02	0.02	4	4,478
02053800	South Fork Roanoke River near Shawsville, VA	100	47	11	2	5	0	0	5	7	15	1	48	241	0.03	0.09	9	8,400
02054500	Roanoke River at Lafayette, VA	34	13	0	0	0	1	0	1	4	0	1	14	68	0.01	0.05	11	4,634
02054530	Roanoke River at Glenvar, VA	71	19	16	2	8	27	2	1	0	0	0	30	176	0.02	0.06	14	7,911
02055000	Roanoke River at Roanoke, VA	5	16	0	0	0	0	0	6	5	0	4	14	50	0.01	0.03	10	4,746
02055100	Tinker Creek near Daleville, VA	35	1	0	7	0	2	2	10	8	50	21	3	139	0.02	0.03	21	6,193
02056000	Roanoke River at Niagara, VA	0	2	0	5	2	0	0	0	6	6	0	0	21	0.00	0.00	19	4,613
02056650	Back Creek near Dundee, VA	63	19	1	0	0	0	4	2	3	18	6	16	132	0.03	0.09	30	4,382
02056900	Blackwater River near Rocky Mount, VA	67	21	2	2	9	0	6	1	15	2	0	16	141	0.03	0.09	4	4,528
02058400	Pigg River near Sandy Level, VA	73	10	5	2	0	15	6	0	1	2	11	24	149	0.03	0.07	10	5,837
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	37	2	0	0	24	30	16	0	0	22	8	13	152	0.07	0.10	19	2,181
02059500	Goose Creek near Huddleston, VA	68	22	6	2	9	6	15	29	5	2	2	32	198	0.05	0.11	37	4,320
02060500	Roanoke River at Altavista, VA	8	0	0	0	11	3	19	2	2	0	0	0	45	0.01	0.00	16	8,390
02061000	Big Otter River near Bedford, VA	28	2	0	0	0	2	0	13	26	30	0	9	110	0.05	0.07	21	2,238
02061500	Big Otter River near Evington, VA	60	20	3	5	11	16	10	23	18	13	5	25	209	0.05	0.09	5	4,485
02062500	Roanoke (Staunton) River at Brookneal, VA	66	34	35	23	19	41	58	21	11	6	23	25	362	0.06	0.08	87	6,573
02064000	Falling River near Naruna, VA	105	55	39	11	44	35	18	39	10	34	19	68	477	0.06	0.11	13	8,399
02065500	Cub Creek at Phenix, VA	93	10	1	12	31	30	30	5	25	1	0	16	254	0.05	0.09	8	5,416
02066000	Roanoke (Staunton) River at Randolph, VA	15	9	2	2	2	2	10	3	8	1	6	5	65	0.01	0.02	36	6,657

Table 13. Number of days with estimated and qualified flows for streamgages in Virginia, water years 1991–2013.—Continued

[A:e, National Water Information System (NWIS) remark code indicating that a daily flow value was estimated; A:1, NWIS remark code indicating that a daily flow value was write-protected without a remark code; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Estimated (A:e)														Write-protected (A:1)		Total daily values
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percentage estimated overall	Percentage estimated during winter	Total	
02069700	South Mayo River near Nettleridge, VA	67	13	5	5	6	30	56	2	10	2	2	15	213	0.05	0.08	7	4,577
02070000	North Mayo River near Spencer, VA	57	9	1	1	0	0	2	2	5	2	0	12	91	0.02	0.07	4	4,381
02071530	Smith River at Smith Riv Church near Woolwine, VA	58	5	0	0	0	0	10	0	21	17	14	14	139	0.02	0.05	28	5,893
02072000	Smith River near Philpott, VA	3	1	8	0	2	6	2	2	8	9	0	6	47	0.01	0.01	18	5,838
02072500	Smith River at Bassett, VA	0	12	6	26	28	20	5	5	0	2	0	1	105	0.02	0.01	41	6,559
02073000	Smith River at Martinsville, VA	0	0	1	0	0	0	5	1	1	2	0	0	12	0.00	0.00	7	4,262
02074500	Sandy River near Danville, VA	106	26	21	30	14	3	29	32	7	35	31	51	385	0.05	0.09	7	8,399
02075045	Dan River at Stp near Danville, VA	45	16	6	1	5	5	20	24	1	11	0	7	141	0.02	0.05	47	6,102
02075500	Dan River at Paces, VA	2	6	0	8	18	9	0	3	2	3	2	2	55	0.01	0.01	32	6,573
02077000	Banister River at Halifax, VA	73	29	8	9	25	64	92	118	107	83	68	57	733	0.09	0.08	38	8,009
02077500	Hyco River near Denniston, VA	28	17	12	21	11	13	0	0	3	15	3	22	145	0.02	0.04	38	6,202
02079640	Allen Creek near Boydton, VA	81	15	2	45	41	98	82	54	68	100	167	63	816	0.12	0.09	9	6,951
03164000	New River near Galax, VA	157	37	16	9	2	10	33	17	6	0	2	52	341	0.05	0.14	9	6,934
03165000	Chestnut Creek at Galax, VA	106	20	0	0	0	2	4	7	17	0	0	31	187	0.03	0.10	61	6,209
03165500	New River at Ivanhoe, VA	18	11	0	5	31	20	31	16	0	3	4	7	146	0.03	0.02	16	5,828
03167000	Reed Creek at Grahams Forge, VA	26	5	4	2	0	1	2	8	10	1	0	13	72	0.02	0.04	27	4,633
03168000	New River at Allisonia, VA	46	12	3	4	0	9	9	3	0	3	3	6	98	0.01	0.04	28	6,938
03170000	Little River at Graysontown, VA	52	12	0	0	0	5	0	0	0	0	0	31	100	0.02	0.08	5	4,745
03171000	New River at Radford, VA	3	3	0	0	0	0	1	0	2	0	7	3	19	0.00	0.01	33	6,929
03173000	Walker Creek at Bane, VA	59	12	0	5	0	2	1	0	0	0	0	23	102	0.01	0.05	12	6,936
03175500	Wolf Creek near Narrows, VA	43	10	0	0	0	0	0	17	9	7	0	19	105	0.02	0.04	12	6,570
03176500	New River at Glen Lyn, VA	6	0	0	2	6	2	7	3	3	0	0	0	29	0.00	0.00	13	6,936
03177710	Bluestone River at Falls Mills, VA	18	13	8	2	3	1	4	0	0	0	3	12	64	0.01	0.04	11	4,637
03207800	Levisa Fork at Big Rock, VA	43	9	5	0	9	0	26	21	19	9	0	27	168	0.02	0.05	42	6,938
03208500	Russell Fork at Haysi, VA	69	24	0	0	16	3	4	5	1	0	0	28	150	0.02	0.07	143	6,937
03208950	Cranes Nest River near Clintwood, VA	60	29	4	6	0	0	2	4	56	48	42	55	306	0.04	0.07	130	8,400
03209000	Pound River below Flannagan Dam, near Haysi, VA	0	0	0	0	0	0	0	11	5	0	0	0	16	0.00	0.00	12	6,937
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	25	0	0	0	0	0	0	0	3	0	0	14	42	0.01	0.03	19	6,203
03473000	South Fork Holston River near Damascus, VA	46	5	0	0	0	5	2	1	3	2	0	16	80	0.01	0.04	38	6,203
03474000	Middle Fork Holston River at Seven Mile Ford, VA	16	5	0	2	0	0	0	1	2	0	0	5	31	0.01	0.02	40	6,187
03475000	Middle Fork Holston River near Meadowview, VA	49	14	2	0	8	3	3	0	2	0	0	19	100	0.02	0.05	57	6,203
03478400	Beaver Creek at Bristol, VA	7	6	0	0	0	0	0	0	0	2	1	0	16	0.00	0.01	43	6,203
03488000	North Fork Holston River near Saltville, VA	54	13	0	0	2	5	0	5	2	0	0	22	103	0.02	0.06	74	6,209
03490000	North Fork Holston River near Gate City, VA	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	3	264
03524000	Clinch River at Cleveland, VA	58	9	3	8	6	4	11	0	9	3	3	16	130	0.02	0.05	87	6,574
03524500	Guest River at Coeburn, VA	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00		119
03527000	Clinch River at Speers Ferry, VA	15	0	0	0	0	0	0	0	26	9	1	3	56	0.01	0.02	48	4,381
03529500	Powell River at Big Stone Gap, VA	9	0	1	0	0	0	0	0	2	3	5	5	25	0.01	0.01	62	4,381
03531500	Powell River near Jonesville, VA	25	1	0	2	0	0	0	4	1	3	0	7	43	0.01	0.02	83	6,572
	Total	9,953	4,160	1,373	1,111	1,551	1,750	2,152	2,063	2,518	2,807	2,373	3,785	35,596	0.04	0.07	4,398	969,759

Table 19   73

Table 19. Number of comparisons of directly measured flow to the rating in effect at the time of measurement relative to divergence thresholds for streamgages in Virginia, water years 1991–2013.

[ΔQ, incidents of difference in flow; %, percent; >, greater than; <, less than; unexplained, lacking an explanation or description of measurement quality in National Water Information System; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of measurement-rating comparisons	Number, ΔQ > 8%	Number, ΔQ > 8%, unexplained	Number, 5% > ΔQ < 8%	Number, 5% > ΔQ < 8%, unexplained	Percentage of unexplained ΔQs
01613900	Hogue Creek near Hayfield, VA	85	2	0	10	1	0.01
01615000	Opequon Creek near Berryville, VA	145	9	2	19	2	0.03
01616100	Dry Marsh Run near Berryville, VA	82	6	3	19	0	0.04
01620500	North River near Stokesville, VA	95	10	4	23	0	0.04
01621050	Muddy Creek at Mount Clinton, VA	123	10	4	30	2	0.05
01622000	North River near Burketown, VA	79	1	1	3	1	0.03
01625000	Middle River near Grottoes, VA	160	2	1	6	0	0.01
01626000	South River near Waynesboro, VA	166	1	0	10	1	0.01
01626850	South River near Dooms, VA	120	3	0	6	0	0.00
01627500	South River at Harriston, VA	98	2	0	6	0	0.00
01628500	South Fork Shenandoah River near Lynnwood, VA	155	2	0	8	1	0.01
01629500	South Fork Shenandoah River near Luray, VA	86	1	0	9	0	0.00
01631000	South Fork Shenandoah River at Front Royal, VA	93	5	0	20	1	0.01
01632000	North Fork Shenandoah River at Cootes Store, VA	119	9	1	28	1	0.02
01632082	Linville Creek at Broadway, VA	190	7	0	16	3	0.02
01632900	Smith Creek near New Market, VA	190	1	0	7	0	0.00
01633000	North Fork Shenandoah River at Mount Jackson, VA	88	1	1	3	2	0.03
01634000	North Fork Shenandoah River near Strasburg, VA	137	6	2	17	1	0.02
01634500	Cedar Creek near Winchester, VA	178	9	0	19	3	0.02
01635500	Passage Creek near Buckton, VA	155	9	2	26	2	0.03
01636316	Spout Run at Rt 621 near Millwood, VA	82	2	1	10	0	0.01
01636690	Piney Run near Lovettsville, VA	86	11	5	18	2	0.08
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	92	7	1	23	0	0.01
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	88	6	2	13	1	0.03
01638480	Catoctin Creek at Taylorstown, VA	99	7	3	10	2	0.05
01643590	Limestone Branch near Leesburg, VA	93	5	2	16	1	0.03
01643700	Goose Creek near Middleburg, VA	89	8	3	16	1	0.04
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	93	5	0	17	1	0.01
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	89	8	0	17	4	0.04
01644000	Goose Creek near Leesburg, VA	98	4	1	10	0	0.01
01644280	Broad Run near Leesburg, VA	83	9	4	18	0	0.05
01645704	Difficult Run above Fox Lake near Fairfax, VA	61	9	1	13	0	0.02
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	60	9	2	14	0	0.03
01646000	Difficult Run near Great Falls, VA	181	10	4	20	2	0.03
01646305	Dead Run at Whann Avenue near Mclean, VA	56	14	3	18	0	0.05
01652500	Fourmile Run at Alexandria, VA	120	8	2	16	1	0.03
01653000	Cameron Run at Alexandria, VA	136	10	6	21	6	0.09
01654000	Accotink Creek near Annandale, VA	95	5	2	19	3	0.05
01656000	Cedar Run near Catlett, VA	171	9	2	16	1	.02
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	63	12	2	15	1	0.05
01658500	South Fork Quantico Creek near Independent Hill, VA	158	25	5	44	4	0.06
01660400	Aquia Creek near Garrisonville, VA	122	16	2	32	5	0.06
01662800	Battle Run near Laurel Mills, VA	163	6	3	17	4	0.04
01663500	Hazel River at Rixeyville, VA	95	1	1	17	0	0.01
01664000	Rappahannock River at Remington, VA	90	6	2	19	0	0.02
01665500	Rapidan River near Ruckersville, VA	124	0	0	7	2	0.02
01666500	Robinson River near Locust Dale, VA	198	2	1	7	0	0.01
01667500	Rapidan River near Culpeper, VA	94	3	1	7	1	0.02
01668000	Rappahannock River near Fredericksburg, VA	81	11	4	19	0	0.05
01669000	Piscataway Creek near Tappahannock, VA	87	2	1	7	1	0.02

Table 19. Number of comparisons of directly measured flow to the rating in effect at the time of measurement relative to divergence thresholds for streamgages in Virginia, water years 1991–2013.—Continued

[ΔQ, incidents of difference in flow; %, percent; >, greater than; <, less than; unexplained, lacking an explanation or description of measurement quality in National Water Information System; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of measurement-rating comparisons	Number, ΔQ > 8%	Number, ΔQ > 8%, unexplained	Number, 5% > ΔQ < 8%	Number, 5% > ΔQ < 8%, unexplained	Percentage of unexplained ΔQs
01669520	Dragon Swamp at Mascot, VA	83	2	0	3	0	0.00
01670400	North Anna River near Partlow, VA	96	5	1	16	2	0.03
01671020	North Anna River at Hart Corner near Doswell, VA	137	3	1	12	5	0.04
01671025	North Anna River above Little River near Doswell, VA	75	8	5	34	3	0.11
01671100	Little River near Doswell, VA	84	1	1	5	0	0.01
01672500	South Anna River near Ashland, VA	88	5	2	16	0	0.02
01673000	Pamunkey River near Hanover, VA	134	5	3	24	0	0.02
01673550	Totopotomoy Creek near Studley, VA	195	10	2	22	10	0.06
01673800	Po River near Spotsylvania, VA	169	7	6	19	2	0.05
01674000	Mattaponi River near Bowling Green, VA	163	27	19	32	0	0.12
01674500	Mattaponi River near Beulahville, VA	139	6	3	17	0	0.02
02011400	Jackson River near Bacova, VA	148	4	3	6	1	0.03
02011460	Back Creek near Sunrise, VA	97	3	1	8	1	0.02
02011470	Back Creek at Sunrise, VA	176	10	6	25	6	0.07
02011490	Little Back Creek near Sunrise, VA	31	6	4	7	0	0.13
02011500	Back Creek near Mountain Grove, VA	161	8	3	16	2	0.03
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	205	21	12	45	4	0.08
02013000	Dunlap Creek near Covington, VA	155	3	2	14	1	0.02
02013100	Jackson River below Dunlap Creek at Covington, VA	151	2	1	12	5	0.04
02014000	Potts Creek near Covington, VA	151	5	4	12	1	0.03
02015700	Bullpasture River at Williamsville, VA	101	1	0	4	2	0.02
02016000	Cowpasture River near Clifton Forge, VA	108	3	1	8	1	0.02
02016500	James River at Lick Run, VA	124	2	1	5	2	0.02
02017500	Johns Creek at New Castle, VA	82	3	0	6	1	0.01
02018000	Craig Creek at Parr, VA	102	0	0	4	0	0.00
02018500	Catawba Creek near Catawba, VA	83	4	2	10	0	0.02
02019500	James River at Buchanan, VA	119	0	0	2	0	0.00
02020500	Calfpasture River above Mill Creek at Goshen, VA	108	1	0	5	0	0.00
02021500	Maury River at Rockbridge Baths, VA	111	3	1	27	5	0.05
02022500	Kerrs Creek near Lexington, VA	92	4	3	12	3	0.07
02024000	Maury River near Buena Vista, VA	91	1	1	13	0	0.01
02024752	James River at Blue Ridge Pkwy near Big Island, VA	42	1	1	8	0	0.02
02024915	Pedlar River at Forest Road near Buena Vista, VA	74	0	0	8	1	0.01
02025500	James River at Holcomb Rock, VA	83	10	6	18	0	0.07
02026000	James River at Bent Creek, VA	57	3	1	10	0	0.02
02027000	Tye River near Lovingston, VA	106	2	2	5	2	0.04
02027500	Piney River at Piney River, VA	86	1	1	3	2	0.03
02028500	Rockfish River near Greenfield, VA	109	1	1	9	2	0.03
02029000	James River at Scottsville, VA	96	1	0	15	0	0.00
02030000	Hardware River below Briery Run near Scottsville, VA	127	2	2	15	5	0.06
02030500	Slate River near Arvonia, VA	119	1	0	7	1	0.01
02031000	Mechums River near White Hall, VA	97	3	1	8	1	0.02
02032250	Moormans River near Free Union, VA	73	5	2	9	1	0.04
02032640	North Fork Rivanna River near Earlysville, VA	168	11	8	21	5	0.08
02034000	Rivanna River at Palmyra, VA	90	3	1	8	3	0.04
02035000	James River at Cartersville, VA	178	29	19	45	4	0.13
02036500	Fine Creek at Fine Creek Mills, VA	165	10	7	25	2	0.05
02037000	James River And Kanawha Canal near Richmond, VA	117	6	0	8	1	0.01
02037500	James River near Richmond, VA	110	5	0	11	1	0.01
02038850	Holiday Creek near Andersonville, VA	94	6	3	26	0	0.03

Table 19   75

Table 19. Number of comparisons of directly measured flow to the rating in effect at the time of measurement relative to divergence thresholds for streamgages in Virginia, water years 1991–2013.—Continued

[ΔQ, incidents of difference in flow; %, percent; >, greater than; <, less than; unexplained, lacking an explanation or description of measurement quality in National Water Information System; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of measurement-rating comparisons	Number, ΔQ > 8%	Number, ΔQ > 8%, unexplained	Number, 5% > ΔQ < 8%	Number, 5% > ΔQ < 8%, unexplained	Percentage of unexplained ΔQs
02039000	Buffalo Creek near Hampden Sydney, VA	164	3	1	4	1	0.01
02039500	Appomattox River at Farmville, VA	89	1	1	8	1	0.02
02040000	Appomattox River at Mattoax, VA	160	2	1	17	3	0.03
02040892	Appomattox River at Route 602 near Mannboro, VA	30	2	0	3	0	0.00
02041000	Deep Creek near Mannboro, VA	170	6	3	14	3	0.04
02041650	Appomattox River at Matoaca, VA	95	5	3	19	0	0.03
02042500	Chickahominy River near Providence Forge, VA	145	12	6	32	1	0.05
02044500	Nottoway River near Rawlings, VA	94	2	0	11	1	0.01
02045500	Nottoway River near Stony Creek, VA	175	3	2	11	3	0.03
02046000	Stony Creek near Dinwiddie, VA	88	2	2	8	2	0.05
02047000	Nottoway River near Sebrell, VA	94	4	2	18	0	0.02
02047500	Blackwater River near Dendron, VA	166	31	2	38	3	0.03
02049500	Blackwater River near Franklin, VA	136	29	3	40	0	0.02
02051000	North Meherrin River near Lunenburg, VA	122	8	4	17	4	0.07
02051500	Meherrin River near Lawrenceville, VA	129	9	1	21	4	0.04
02052000	Meherrin River at Emporia, VA	88	7	2	9	1	0.03
02053800	South Fork Roanoke River near Shawsville, VA	169	6	3	12	2	0.03
02054500	Roanoke River at Lafayette, VA	89	1	0	9	4	0.04
02054530	Roanoke River at Glenvar, VA	160	2	1	8	5	0.04
02055000	Roanoke River at Roanoke, VA	103	5	5	7	1	0.06
02055100	Tinker Creek near Daleville, VA	135	7	5	13	2	0.05
02056000	Roanoke River at Niagara, VA	89	2	1	3	1	0.02
02056650	Back Creek near Dundee, VA	88	0	0	8	4	0.05
02056900	Blackwater River near Rocky Mount, VA	83	2	1	5	1	0.02
02058400	Pigg River near Sandy Level, VA	114	3	2	17	1	0.03
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	47	0	0	1	1	0.02
02059500	Goose Creek near Huddleston, VA	88	2	0	7	1	0.01
02060500	Roanoke River at Altavista, VA	160	3	3	23	4	0.04
02061000	Big Otter River near Bedford, VA	51	5	4	8	1	0.10
02061500	Big Otter River near Evington, VA	95	1	0	4	1	0.01
02062500	Roanoke (Staunton) River at Brookneal, VA	134	8	1	19	1	0.01
02064000	Falling River near Naruna, VA	161	3	1	8	1	0.01
02065500	Cub Creek at Phenix, VA	110	6	2	7	1	0.03
02066000	Roanoke (Staunton) River at Randolph, VA	138	12	5	26	2	0.05
02069700	South Mayo River near Nettleridge, VA	84	2	1	6	2	0.04
02070000	North Mayo River near Spencer, VA	78	2	1	6	2	0.04
02071530	Smith River at Smith Riv Church near Woolwine, VA	117	4	1	13	8	0.08
02072000	Smith River near Philpott, VA	116	4	1	13	3	0.03
02072500	Smith River at Bassett, VA	140	3	1	17	1	0.01
02073000	Smith River at Martinsville, VA	71	2	1	5	0	0.01
02074500	Sandy River near Danville, VA	158	2	1	7	0	0.01
02075045	Dan River at Stp near Danville, VA	122	10	1	24	0	0.01
02075500	Dan River at Paces, VA	132	14	3	21	0	0.02
02077000	Banister River at Halifax, VA	102	20	9	32	1	0.10
02077500	Hyco River near Denniston, VA	122	5	0	13	0	0.00
02079640	Allen Creek near Boydton, VA	153	8	4	20	1	0.03
03164000	New River near Galax, VA	143	2	1	6	1	0.01
03165000	Chestnut Creek at Galax, VA	134	5	4	9	1	0.04
03165500	New River at Ivanhoe, VA	123	3	3	8	2	0.04
03167000	Reed Creek at Grahams Forge, VA	102	0	0	0	0	0.00

Table 19. Number of comparisons of directly measured flow to the rating in effect at the time of measurement relative to divergence thresholds for streamgages in Virginia, water years 1991–2013.—Continued

[ΔQ, incidents of difference in flow; %, percent; >, greater than; <, less than; unexplained, lacking an explanation or description of measurement quality in National Water Information System; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Number of measurement-rating comparisons	Number, ΔQ > 8%	Number, ΔQ > 8%, unexplained	Number, 5% > ΔQ < 8%	Number, 5% > ΔQ < 8%, unexplained	Percentage of unexplained ΔQs
03168000	New River at Allisonia, VA	134	1	1	9	4	0.04
03170000	Little River at Graysontown, VA	110	2	0	6	1	0.01
03171000	New River at Radford, VA	128	3	1	10	1	0.02
03173000	Walker Creek at Bane, VA	155	6	1	17	5	0.04
03175500	Wolf Creek near Narrows, VA	146	3	1	9	2	0.02
03176500	New River at Glen Lyn, VA	149	3	1	9	0	0.01
03177710	Bluestone River at Falls Mills, VA	129	10	9	29	14	0.18
03207800	Levisa Fork at Big Rock, VA	151	0	0	7	3	0.02
03208500	Russell Fork at Haysi, VA	151	3	1	9	0	0.01
03208950	Cranes Nest River near Clintwood, VA	186	21	11	29	2	0.07
03209000	Pound River below Flannagan Dam, near Haysi, VA	140	5	2	9	1	0.02
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	142	5	3	7	0	0.02
03473000	South Fork Holston River near Damascus, VA	126	2	1	10	3	0.03
03474000	Middle Fork Holston River at Seven Mile Ford, VA	135	6	3	18	0	0.02
03475000	Middle Fork Holston River near Meadowview, VA	140	2	1	9	2	0.02
03478400	Beaver Creek at Bristol, VA	163	4	4	16	8	0.07
03488000	North Fork Holston River near Saltville, VA	144	3	0	4	0	0.00
03490000	North Fork Holston River near Gate City, VA	5	1	0	1	0	0.00
03524000	Clinch River at Cleveland, VA	149	1	1	4	1	0.01
03524500	Guest River at Coeburn, VA	2	0	0	0	0	0.00
03527000	Clinch River at Speers Ferry, VA	101	0	0	7	2	0.02
03529500	Powell River at Big Stone Gap, VA	109	3	2	7	1	0.03
03531500	Powell River near Jonesville, VA	138	1	1	4	0	0.01
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	20	2	1	6	0	0.05
	Total	**20,380**	**1,063**	**451**	**2,482**	**287**	**0.04**

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Table 21. Number of days of available Q_{prev} record for streamgages in Virginia, by streamgage and month, and earliest date the records are available, during water years 1991–2013.

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	Number of daily observations of Q_{prev}, by month												Total daily observations	Total, in years
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
01613900	Hogue Creek near Hayfield, VA	11/27/2001	372	339	372	360	372	360	372	372	360	341	334	372	4,326	11.8
01615000	Opequon Creek near Berryville, VA	11/28/1990	558	509	558	540	558	540	558	558	540	515	483	549	6,466	17.7
01616100	Dry Marsh Run near Berryville, VA	9/5/2002	341	311	341	330	341	330	341	341	356	341	330	341	4,044	11.1
01620500	North River near Stokesville, VA	10/3/2001	372	339	372	360	372	360	372	372	360	370	360	372	4,381	12.0
01621050	Muddy Creek at Mount Clinton, VA	1/28/1997	500	480	527	510	527	510	527	527	510	496	480	496	6,090	16.7
01622000	North River near Burketown, VA	10/5/2001	372	339	372	360	372	360	372	372	360	368	360	372	4,379	12.0
01625000	Middle River near Grottoes, VA	12/3/1990	713	650	713	690	713	690	713	713	690	682	660	711	8,338	22.8
01626000	South River near Waynesboro, VA	12/3/1990	713	650	713	690	713	690	713	713	690	682	660	711	8,338	22.8
01626850	South River near Dooms, VA	12/3/1990	434	396	434	420	434	420	434	434	420	421	420	442	5,109	14.0
01627500	South River at Harriston, VA	2/2/2001	372	366	403	390	403	390	403	403	390	372	360	372	4,624	12.7
01628500	South Fork Shenandoah River near Lynnwood, VA	12/3/1990	713	650	713	690	713	690	713	713	690	682	660	711	8,338	22.8
01629500	South Fork Shenandoah River near Luray, VA	10/12/2001	372	339	372	360	372	360	372	372	360	361	360	372	4,372	12.0
01631000	South Fork Shenandoah River at Front Royal, VA	10/5/2001	372	339	372	360	372	360	372	372	360	368	360	372	4,379	12.0
01632000	North Fork Shenandoah River at Cootes Store, VA	4/22/1997	496	452	496	489	527	510	527	527	510	496	480	496	6,006	16.4
01632082	Linville Creek at Broadway, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
01632900	Smith Creek near New Market, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
01633000	North Fork Shenandoah River at Mount Jackson, VA	5/9/2001	372	339	372	360	395	390	403	403	390	372	360	372	4,528	12.4
01634000	North Fork Shenandoah River near Strasburg, VA	12/12/1996	527	480	527	510	527	510	527	527	510	496	480	516	6,137	16.8
01634500	Cedar Creek near Winchester, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
01635500	Passage Creek near Buckton, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
01636316	Spout Run at Rt 621 near Millwood, VA	10/18/2002	341	311	341	330	341	330	341	341	330	324	330	341	4,001	11.0
01636690	Piney Run near Lovettsville, VA	11/28/2001	372	339	372	360	372	360	372	372	360	341	333	372	4,325	11.8
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	9/6/2001	372	339	372	360	372	360	372	372	385	372	360	372	4,408	12.1
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	9/6/2001	372	339	372	360	372	360	372	372	385	372	360	372	4,408	12.1
01638480	Catoctin Creek at Taylorstown, VA	11/5/2001	372	339	372	360	372	360	372	372	360	341	356	372	4,348	11.9
01643590	Limestone Branch near Leesburg, VA	9/21/2001	372	339	372	360	372	360	372	372	370	372	360	372	4,393	12.0
01643700	Goose Creek near Middleburg, VA	9/7/2001	372	339	372	360	372	360	372	372	384	367	360	372	4,402	12.1
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	10/9/2001	372	339	372	360	372	360	372	372	360	364	360	372	4,375	12.0
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	9/6/2001	372	339	372	360	372	360	372	372	385	372	360	372	4,408	12.1
01644000	Goose Creek near Leesburg, VA	3/19/2001	372	339	385	390	403	390	403	403	390	372	360	372	4,579	12.5
01644280	Broad Run near Leesburg, VA	4/10/2002	341	311	341	351	372	360	372	372	360	341	330	341	4,192	11.5
01645704	Difficult Run above Fox Lake near Fairfax, VA	10/25/2007	186	170	186	180	186	180	186	186	180	162	180	186	2,168	5.9
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	10/25/2007	186	170	186	180	186	180	186	186	180	162	180	186	2,168	5.9
01646000	Difficult Run near Great Falls, VA	11/27/1990	713	650	713	690	713	690	713	713	690	682	664	713	8,344	22.8
01646305	Dead Run at Whann Avenue near Mclean, VA	3/7/2008	155	141	180	180	186	180	186	186	180	155	150	155	2,034	5.6
01652500	Fourmile Run at Alexandria, VA	10/16/1998	465	424	465	450	465	450	465	465	450	450	450	465	5,464	15.0
01653000	Cameron Run at Alexandria, VA	12/16/1996	527	480	527	510	527	510	527	527	510	496	480	512	6,133	16.8
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	2/9/2012	31	49	62	60	62	60	62	62	60	31	30	31	600	1.6
01654000	Accotink Creek near Annandale, VA	11/26/2001	372	339	372	360	372	360	372	372	360	341	335	372	4,327	11.8
01656000	Cedar Run near Catlett, VA	11/27/1990	713	650	713	690	713	690	713	713	689	682	664	713	8,343	22.8

Table 21. Number of days of available Q_{prev} record for streamgages in Virginia, by streamgage and month, and earliest date the records are available, during water years 1991–2013.—Continued

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total daily observations	Total, in years
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	10/24/2007	186	170	186	180	186	180	186	186	180	163	180	186	2,169	5.9
01658500	South Fork Quantico Creek near Independent Hill, VA	11/25/1996	527	480	527	510	527	510	527	527	510	496	486	527	6,154	16.8
01660400	Aquia Creek near Garrisonville, VA	1/19/2000	416	396	434	420	434	420	434	434	420	403	390	403	5,004	13.7
01662800	Battle Run near Laurel Mills, VA	10/11/1990	651	593	651	630	651	630	630	620	600	614	630	651	7,551	20.7
01663500	Hazel River at Rixeyville, VA	11/1/2001	372	339	372	360	372	360	372	372	360	341	360	372	4,352	11.9
01664000	Rappahannock River at Remington, VA	11/1/2001	372	339	372	360	372	360	372	372	360	341	360	372	4,352	11.9
01665500	Rapidan River near Ruckersville, VA	12/9/1998	465	424	465	450	465	450	465	465	450	434	420	457	5,410	14.8
01666500	Robinson River near Locust Dale, VA	10/15/1990	713	650	713	690	713	690	713	713	690	699	690	713	8,387	23.0
01667500	Rapidan River near Culpeper, VA	3/23/2001	372	339	381	390	403	390	403	403	390	372	360	372	4,575	12.5
01668000	Rappahannock River near Fredericksburg, VA	12/18/2000	403	367	403	390	403	390	403	403	390	372	360	386	4,670	12.8
01669000	Piscataway Creek near Tappahannock, VA	10/2/2001	372	339	372	360	372	360	372	372	360	371	360	372	4,382	12.0
01669520	Dragon Swamp at Mascot, VA	6/11/2001	372	339	372	360	372	380	403	403	390	372	360	372	4,495	12.3
01670400	North Anna River near Partlow, VA	11/26/1990	341	311	346	360	372	360	372	372	360	310	305	341	4,150	11.4
01671020	North Anna River at Hart Corner near Doswell, VA	10/1/1998	465	424	465	450	465	450	465	465	450	465	450	465	5,479	15.0
01671025	North Anna River above Little River near Doswell, VA	11/10/2004	272	252	260	266	267	260	279	279	265	247	250	259	3,156	8.6
01671100	Little River near Doswell, VA	9/17/2001	372	339	372	360	372	360	372	372	374	372	360	372	4,397	12.0
01672500	South Anna River near Ashland, VA	6/10/1997	310	283	310	300	310	321	356	372	360	310	300	310	3,842	10.5
01673000	Pamunkey River near Hanover, VA	5/7/1997	496	452	496	480	521	510	527	527	510	496	480	496	5,991	16.4
01673550	Totopotomoy Creek near Studley, VA	11/26/1990	713	650	713	690	713	690	713	713	690	682	665	713	8,345	22.8
01673800	Po River near Spotsylvania, VA	11/27/1990	713	650	713	690	713	690	713	713	690	682	664	713	8,344	22.8
01674000	Mattaponi River near Bowling Green, VA	11/26/1990	713	650	713	690	713	690	713	713	690	682	665	713	8,345	22.8
01674500	Mattaponi River near Beulahville, VA	10/4/1995	559	509	558	540	558	540	558	558	539	555	540	558	6,572	18.0
02011400	Jackson River near Bacova, VA	11/15/1994	589	537	589	570	589	570	589	589	570	558	556	589	6,895	18.9
02011460	Back Creek near Sunrise, VA	8/14/2001	372	339	372	360	372	360	372	390	390	372	360	372	4,431	12.1
02011470	Back Creek at Sunrise, VA	11/15/1994	589	537	589	570	589	570	589	589	570	558	556	589	6,895	18.9
02011490	Little Back Creek near Sunrise, VA	10/23/2003	310	283	310	300	310	300	310	310	300	288	300	310	3,631	9.9
02011500	Back Creek near Mountain Grove, VA	11/15/1994	589	537	589	570	589	570	589	589	570	558	556	589	6,895	18.9
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	11/16/1994	589	537	589	570	589	570	589	589	570	558	555	589	6,894	18.9
02013000	Dunlap Creek near Covington, VA	10/5/1995	558	509	558	540	558	540	558	558	540	554	540	558	6,571	18.0
02013100	Jackson River below Dunlap Creek at Covington, VA	8/30/1995	558	509	558	540	558	540	558	560	570	558	540	558	6,607	18.1
02014000	Potts Creek near Covington, VA	4/6/1995	558	509	558	565	589	570	589	589	570	558	540	558	6,753	18.5
02015700	Bullpasture River at Williamsville, VA	10/15/1998	465	424	465	450	465	450	465	465	450	451	450	465	5,465	15.0
02016000	Cowpasture River near Clifton Forge, VA	3/23/2000	403	367	412	420	434	420	434	434	420	403	390	403	4,940	13.5
02016500	James River at Lick Run, VA	5/18/1998	465	424	465	450	479	480	496	496	480	465	450	465	5,615	15.4
02017500	Johns Creek at New Castle, VA	12/4/2001	372	339	372	360	372	360	372	372	360	341	330	369	4,319	11.8
02018000	Craig Creek at Parr, VA	11/5/2001	372	339	372	360	372	360	372	372	360	341	356	372	4,348	11.9
02018500	Catawba Creek near Catawba, VA	12/4/2001	372	339	372	360	372	360	372	372	360	341	330	369	4,319	11.8
02019500	James River at Buchanan, VA	7/15/1998	465	424	465	450	465	450	482	496	480	465	450	465	5,557	15.2
02020500	Calfpasture River above Mill Creek at Goshen, VA	12/8/1998	465	424	465	450	465	450	465	465	450	434	420	458	5,411	14.8
02021500	Maury River at Rockbridge Baths, VA	1/21/1997	507	480	527	510	527	510	527	527	510	496	480	496	6,097	16.7

Table 21   79

Table 21. Number of days of available Q_{prev} record for streamgages in Virginia, by streamgage and month, and earliest date the records are available, during water years 1991–2013.—Continued

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total daily observations	Total, in years
02022500	Kerrs Creek near Lexington, VA	5/15/2001	372	339	372	360	389	390	403	403	390	372	360	372	4,522	12.4
02024000	Maury River near Buena Vista, VA	11/18/1999	434	396	434	420	434	420	434	434	420	403	403	434	5,066	13.9
02024752	James River at Blue Ridge Pkwy near Big Island, VA	11/17/2006	217	198	217	210	217	210	217	217	210	186	194	217	2,510	6.9
02024915	Pedlar River at Forest Road near Buena Vista, VA	12/2/2002	341	311	341	330	341	330	341	341	324	296	300	340	3,936	10.8
02025500	James River at Holcomb Rock, VA	3/30/1999	434	396	436	450	465	450	465	465	450	434	420	434	5,299	14.5
02026000	James River at Bent Creek, VA	9/19/2003	310	283	310	300	310	300	310	310	312	310	300	310	3,665	10.0
02027000	Tye River near Lovingston, VA	12/14/1998	465	424	465	450	465	450	465	465	450	434	420	452	5,405	14.8
02027500	Piney River at Piney River, VA	5/15/2001	372	339	372	360	389	390	403	403	390	372	360	372	4,522	12.4
02028500	Rockfish River near Greenfield, VA	9/9/1998	465	424	465	450	465	450	465	465	472	465	450	465	5,501	15.1
02029000	James River at Scottsville, VA	1/14/1997	514	480	527	510	527	510	527	527	510	496	480	496	6,104	16.7
02030000	Hardware River below Briery Run near Scottsville, VA	11/6/1997	496	452	496	480	496	480	496	496	480	465	475	496	5,808	15.9
02030500	Slate River near Arvonia, VA	11/27/1990	403	367	403	390	403	390	403	433	420	387	364	403	4,766	13.0
02031000	Mechums River near White Hall, VA	11/27/2001	372	339	372	360	372	360	372	352	330	333	334	372	4,268	11.7
02032250	Moormans River near Free Union, VA	7/8/2005	248	226	248	240	248	240	272	279	270	248	240	248	3,007	8.2
02032640	North Fork Rivanna River near Earlysville, VA	12/10/1993	620	565	620	600	620	600	620	620	600	589	570	611	7,235	19.8
02034000	Rivanna River at Palmyra, VA	6/29/2001	372	339	372	360	372	362	403	403	390	372	360	372	4,477	12.3
02035000	James River at Cartersville, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
02036500	Fine Creek at Fine Creek Mills, VA	12/3/1990	713	650	713	690	713	690	713	713	690	682	660	711	8,338	22.8
02037000	James River And Kanawha Canal near Richmond, VA	5/3/2001	372	339	372	360	401	390	403	403	390	372	360	372	4,534	12.4
02037500	James River near Richmond, VA	1/6/1998	491	452	496	480	496	480	496	496	480	465	450	465	5,747	15.7
02038850	Holiday Creek near Andersonville, VA	8/10/2001	372	339	372	360	372	360	372	394	390	372	360	372	4,435	12.1
02039000	Buffalo Creek near Hampden Sydney, VA	12/5/1990	713	650	713	690	713	690	713	713	690	682	660	709	8,336	22.8
02039500	Appomattox River at Farmville, VA	5/18/2001	372	339	372	360	386	390	403	403	390	372	360	372	4,519	12.4
02040000	Appomattox River at Mattoax, VA	12/3/1990	713	650	713	690	713	690	713	713	690	682	660	711	8,338	22.8
02040892	Appomattox River at Route 602 near Mannboro, VA	9/27/2011	62	57	62	60	62	60	62	62	64	62	60	62	735	2.0
02041000	Deep Creek near Mannboro, VA	12/3/1990	713	650	713	690	713	690	713	712	690	682	660	711	8,337	22.8
02041650	Appomattox River at Matoaca, VA	7/26/2000	403	367	403	390	403	390	409	430	420	403	390	403	4,811	13.2
02042500	Chickahominy River near Providence Forge, VA	2/26/1997	496	455	527	510	527	510	515	521	510	496	480	496	6,043	16.5
02044500	Nottoway River near Rawlings, VA	8/7/2001	372	339	372	360	372	360	372	397	390	372	360	372	4,438	12.2
02045500	Nottoway River near Stony Creek, VA	12/4/1990	713	650	713	690	713	690	713	713	690	682	660	710	8,337	22.8
02046000	Stony Creek near Dinwiddie, VA	12/11/2001	372	339	372	360	372	360	372	372	360	341	330	362	4,312	11.8
02047000	Nottoway River near Sebrell, VA	12/13/2000	403	367	403	390	403	390	403	403	387	372	360	391	4,672	12.8
02047500	Blackwater River near Dendron, VA	11/28/1990	709	650	713	690	713	667	687	713	686	636	633	690	8,187	22.4
02049500	Blackwater River near Franklin, VA	6/10/1997	496	452	496	480	496	501	527	527	510	496	480	496	5,957	16.3
02051000	North Meherrin River near Lunenburg, VA	2/12/1998	465	441	496	480	496	480	496	496	480	465	450	465	5,710	15.6
02051500	Meherrin River near Lawrenceville, VA	3/6/1997	496	452	522	510	527	510	527	527	510	496	480	496	6,053	16.6
02052000	Meherrin River at Emporia, VA	8/7/2001	372	339	372	360	372	360	372	397	390	372	360	372	4,438	12.2
02053800	South Fork Roanoke River near Shawsville, VA	10/23/1990	713	650	713	690	713	690	713	713	690	691	690	713	8,379	22.9
02054500	Roanoke River at Lafayette, VA	3/20/2001	372	339	384	390	403	390	403	403	390	372	360	372	4,578	12.5
02054530	Roanoke River at Glenvar, VA	4/21/1992	651	593	651	640	682	660	682	682	660	651	630	651	7,833	21.4

Table 21. Number of days of available Q_{prev} record for streamgages in Virginia, by streamgage and month, and earliest date the records are available, during water years 1991–2013.—Continued

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total daily observations	Total, in years
02055000	Roanoke River at Roanoke, VA	11/20/2000	403	367	403	390	403	390	403	403	390	372	371	403	4,698	12.9
02055100	Tinker Creek near Daleville, VA	11/13/1996	527	480	527	510	527	510	527	527	510	496	498	527	6,166	16.9
02056000	Roanoke River near Niagara, VA	4/10/2001	372	339	372	381	403	390	403	403	390	372	360	372	4,557	12.5
02056650	Back Creek near Dundee, VA	11/7/2001	372	339	372	360	372	360	372	372	360	341	354	372	4,346	11.9
02056900	Blackwater River near Rocky Mount, VA	6/20/2001	372	339	372	360	372	371	403	403	390	372	360	372	4,486	12.3
02058400	Pigg River near Sandy Level, VA	11/7/1997	496	452	496	480	496	480	496	496	480	465	474	496	5,807	15.9
02059485	Goose Creek at Rt 747 near Bunker Hill, VA	11/28/2007	186	170	186	180	186	180	186	186	180	155	153	186	2,134	5.8
02059500	Goose Creek near Huddleston, VA	1/28/2002	345	339	372	360	372	360	372	372	360	341	330	341	4,264	11.7
02060500	Roanoke River at Altavista, VA	11/15/1990	713	650	713	690	713	690	713	713	690	682	676	713	8,356	22.9
02061000	Big Otter River near Bedford, VA	10/11/2007	186	170	186	180	186	180	186	186	180	176	180	186	2,182	6.0
02061500	Big Otter River near Evington, VA	8/2/2001	372	339	372	360	372	360	372	402	390	372	360	372	4,443	12.2
02062500	Roanoke (Staunton) River at Brookneal, VA	11/7/1995	558	509	558	540	558	540	558	558	540	527	534	558	6,538	17.9
02064000	Falling River near Naruna, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
02065500	Cub Creek at Phenix, VA	1/28/1999	438	424	465	450	465	450	465	465	450	434	420	434	5,360	14.7
02066000	Roanoke (Staunton) River at Randolph, VA	8/30/1995	558	509	558	540	558	540	558	560	570	558	540	558	6,607	18.1
02069700	South Mayo River near Nettleridge, VA	5/8/2001	372	339	372	360	396	390	403	403	390	372	360	372	4,529	12.4
02070000	North Mayo River near Spencer, VA	12/5/2001	372	339	372	360	372	360	372	372	360	341	330	368	4,318	11.8
02071530	Smith River at Smith Riv Church near Woolwine, VA	10/7/1997	496	452	496	480	496	480	496	496	480	490	480	496	5,838	16.0
02072000	Smith River near Philpott, VA	4/28/1998	465	424	465	453	496	480	496	496	480	465	450	465	5,635	15.4
02072500	Smith River at Bassett, VA	1/3/1996	556	509	558	540	558	540	558	558	540	527	510	527	6,481	17.7
02073000	Smith River at Martinsville, VA	3/20/2002	341	311	353	360	372	360	372	372	360	341	330	341	4,213	11.5
02074500	Sandy River near Danville, VA	11/29/1990	713	650	713	690	713	690	713	713	690	682	662	713	8,342	22.8
02075045	Dan River at Stp near Danville, VA	3/10/1997	496	452	518	510	527	510	527	527	510	496	480	496	6,049	16.6
02075500	Dan River at Paces, VA	11/6/1995	558	509	558	540	558	540	558	558	540	527	535	558	6,539	17.9
02077000	Banister River at Halifax, VA	8/22/1991	651	593	657	660	682	645	635	621	636	655	627	648	7,710	21.1
02077500	Hyco River near Denniston, VA	11/13/1996	527	480	527	510	527	510	527	527	510	496	498	527	6,166	16.9
02079640	Allen Creek near Boydton, VA	12/5/1990	589	537	589	570	589	570	589	589	570	547	512	585	6,836	18.7
03164000	New River near Galax, VA	11/18/1994	589	537	589	570	589	570	589	589	570	558	553	589	6,892	18.9
03165000	Chestnut Creek at Galax, VA	11/22/1996	527	480	527	510	527	510	527	527	510	496	489	527	6,157	16.9
03165500	New River at Ivanhoe, VA	12/19/1997	496	452	496	480	496	480	496	496	480	465	450	478	5,765	15.8
03167000	Reed Creek at Grahams Forge, VA	3/21/2001	372	339	383	390	403	390	403	403	390	372	360	372	4,577	12.5
03168000	New River at Allisonia, VA	11/14/1994	589	537	589	570	589	570	589	589	570	558	557	589	6,896	18.9
03170000	Little River at Graysontown, VA	11/14/2000	403	367	403	390	403	390	403	403	390	372	377	403	4,704	12.9
03171000	New River at Radford, VA	12/29/1994	589	537	589	570	589	570	589	589	570	558	540	561	6,851	18.8
03173000	Walker Creek at Bane, VA	11/16/1994	589	537	589	570	589	570	589	589	570	558	555	589	6,894	18.9
03175500	Wolf Creek near Narrows, VA	11/16/1994	558	508	558	540	558	540	558	558	540	496	514	558	6,486	17.8
03176500	New River at Glen Lyn, VA	11/16/1994	589	537	589	570	589	570	589	589	570	558	555	589	6,894	18.9
03177710	Bluestone River at Falls Mills, VA	10/7/1993	403	367	403	387	372	360	372	372	360	366	360	396	4,518	12.4
03207800	Levisa Fork at Big Rock, VA	11/14/1994	589	537	589	570	589	570	589	589	570	558	557	589	6,896	18.9
03208500	Russell Fork at Haysi, VA	11/15/1994	589	537	589	570	589	570	589	589	570	558	556	589	6,895	18.9

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Table 21. Number of days of available Q_{prev} record for streamgages in Virginia, by streamgage and month, and earliest date the records are available, during water years 1991–2013.—Continued

[Q_{prev}, the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Earliest date	Number of daily observations of Q_{prev}, by month												Total daily observations	Total, in years
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
03208950	Cranes Nest River near Clintwood, VA	11/20/1990	713	650	713	690	713	690	713	713	690	682	671	713	8,351	22.9
03209000	Pound River below Flannagan Dam, near Haysi, VA	11/15/1994	589	537	589	570	589	570	589	589	570	558	556	589	6,895	18.9
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	11/18/1996	527	480	527	510	527	510	527	527	510	496	493	527	6,161	16.9
03473000	South Fork Holston River near Damascus, VA	11/18/1996	527	480	527	510	527	510	527	527	510	493	493	527	6,158	16.9
03474000	Middle Fork Holston River at Seven Mile Ford, VA	12/2/1996	527	480	527	510	527	510	527	527	510	496	480	526	6,147	16.8
03475000	Middle Fork Holston River near Meadowview, VA	11/18/1996	527	480	527	510	527	510	527	527	510	496	493	527	6,161	16.9
03478400	Beaver Creek at Bristol, VA	11/14/1996	527	480	527	510	527	510	527	527	510	496	497	527	6,165	16.9
03488000	North Fork Holston River near Saltville, VA	11/1/1996	527	480	527	510	527	510	527	527	510	496	510	527	6,178	16.9
03490000	North Fork Holston River near Gate City, VA	1/17/2013	15	28	31	30	31	30	31	31	30				257	0.7
03524000	Clinch River at Cleveland, VA	11/13/1995	558	509	558	540	558	540	558	558	540	527	528	558	6,532	17.9
03524500	Guest River at Coeburn, VA	7/22/2013							10	31	30				71	0.2
03527000	Clinch River at Speers Ferry, VA	11/7/2001	372	339	372	360	372	360	372	372	360	341	354	372	4,346	11.9
03529500	Powell River at Big Stone Gap, VA	11/6/2001	372	339	372	360	372	360	372	372	360	341	355	372	4,347	11.9
03531500	Powell River near Jonesville, VA	11/29/1995	558	509	558	540	558	540	558	558	540	527	512	558	6,516	17.8

Table 22. Control and rating stability assessments made by senior hydrographers in the Virginia Water Science Center and Virginia Department of Environmental Quality for streamgages in Virginia active September 30, 2013.

[–, no response; E, excellent; G, good; F, fair; P, poor. Averages were computed by assigning numeric equivalents of 4 for excellent, 3 for good, 2 for fair, and 1 for poor. *Italicized* sites were not characterized by any hydrographer in response to questionnaires and were assigned scores by the authors from other descriptions. Individual hydrographers are identified by number, chronologically in the order that questionnaires were received; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Hydrographer										Number of replies	Average stability score
		1	2	3	4	5	6	7	8	9	10		
01613900	Hogue Creek near Hayfield, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01615000	Opequon Creek near Berryville, VA	–	–	–	G	–	–	–	G	–	–	2	3.0
01616100	Dry Marsh Run near Berryville, VA	–	–	E	F	–	–	–	F	–	–	3	2.7
01620500	North River near Stokesville, VA	–	–	F	G	–	–	–	–	G	–	3	2.7
01621050	Muddy Creek at Mount Clinton, VA	–	–	G	G	–	–	–	–	G	–	3	3.0
01622000	North River near Burketown, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01625000	Middle River near Grottoes, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01626000	South River near Waynesboro, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01626850	South River near Dooms, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01627500	South River at Harriston, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01628500	South Fork Shenandoah River near Lynnwood, VA	–	–	G	E	–	–	–	–	–	–	2	3.5
01629500	South Fork Shenandoah River near Luray, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01631000	South Fork Shenandoah River at Front Royal, VA	–	–	G	G	–	–	–	G	–	–	3	3.0
01632000	North Fork Shenandoah River at Cootes Store, VA	–	–	F	G	–	–	–	G	G	–	4	2.8
01632082	Linville Creek at Broadway, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01632900	Smith Creek near New Market, VA	–	–	–	F	–	–	–	G	–	–	2	2.5
01633000	North Fork Shenandoah River at Mount Jackson, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01634000	North Fork Shenandoah River near Strasburg, VA	–	–	E	G	–	–	–	G	–	–	3	3.3
01634500	Cedar Creek near Winchester, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
01635500	Passage Creek near Buckton, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
01636316	Spout Run at Rt 621 near Millwood, VA	–	–	E	–	–	–	–	G	–	–	2	3.5
01636690	Piney Run near Lovettsville, VA	–	–	G	–	–	–	–	P	–	–	2	2.0
01638350	South Fork Catoctin Creek at Rt 698 near Waterford, VA	–	–	G	–	–	–	–	P	–	–	2	2.0
01638420	North Fork Catoctin Creek at Rt 681 near Waterford, VA	–	–	G	–	–	–	–	G	–	–	2	3.0
01638480	Catoctin Creek at Taylorstown, VA	P	–	–	P	–	–	–	–	–	–	2	1.0
01643590	Limestone Branch near Leesburg, VA	–	–	F	–	–	–	–	G	–	–	2	2.5
01643700	Goose Creek near Middleburg, VA	–	–	G	–	–	–	–	F	–	–	2	2.5
01643805	North Fork Goose Creek at Rt 729 near Lincoln, VA	–	–	P	–	–	–	–	F	–	–	2	1.5
01643880	Beaverdam Creek at Rt 734 near Mountville, VA	–	–	F	–	–	–	–	G	–	–	2	2.5
01644000	Goose Creek near Leesburg, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
01644280	Broad Run near Leesburg, VA	–	G	F	–	–	–	–	–	–	–	2	2.5
01645704	Difficult Run above Fox Lake near Fairfax, VA	–	F	P	–	–	G	–	–	–	–	3	2.0
01645762	South Fork Little Difficult Run above Mouth near Vienna, VA	–	F	P	–	–	P	–	–	–	–	3	1.3
01646000	Difficult Run near Great Falls, VA	–	G	G	G	–	F	–	–	–	–	4	2.8
01646305	Dead Run at Whann Avenue near Mclean, VA	–	F	P	–	–	P	–	–	–	–	3	1.3
01652500	Fourmile Run at Alexandria, VA	–	F	F	–	–	P	–	–	–	–	3	1.7
01653000	Cameron Run at Alexandria, VA	–	F	F	–	–	P	–	–	–	–	3	1.7
0165389205	Accotink Creek near Ranger Road at Fairfax, VA	–	–	G	–	–	–	–	–	–	–	1	3.0
01654000	Accotink Creek near Annandale, VA	–	P	P	P	–	P	–	–	–	–	4	1.0
01656000	Cedar Run near Catlett, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	–	F	F	–	–	G	–	–	–	–	3	2.3
01658500	South Fork Quantico Creek near Independent Hill, VA	–	–	F	–	–	F	–	–	–	–	2	2.0
01660400	Aquia Creek near Garrisonville, VA	–	–	F	–	–	G	–	–	G	–	3	2.7
01662800	Battle Run near Laurel Mills, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
01663500	Hazel River at Rixeyville, VA	–	–	G	–	–	G	–	–	G	–	3	3.0

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Table 22. Control and rating stability assessments made by senior hydrographers in the Virginia Water Science Center and Virginia Department of Environmental Quality for streamgages in Virginia active September 30, 2013.—Continued

[–, no response; E, excellent; G, good; F, fair; P, poor. Averages were computed by assigning numeric equivalents of 4 for excellent, 3 for good, 2 for fair, and 1 for poor. *Italicized* sites were not characterized by any hydrographer in response to questionnaires and were assigned scores by the authors from other descriptions. Individual hydrographers are identified by number, chronologically in the order that questionnaires were received; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Hydrographer										Number of replies	Average stability score
		1	2	3	4	5	6	7	8	9	10		
01664000	Rappahannock River at Remington, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
01665500	Rapidan River near Ruckersville, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
01666500	Robinson River near Locust Dale, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
01667500	Rapidan River near Culpeper, VA	F	–	–	E	–	–	–	–	–	–	2	3.0
01668000	Rappahannock River near Fredericksburg, VA	–	–	F	–	–	G	–	–	G	–	3	2.7
01669000	Piscataway Creek near Tappahannock, VA	P	–	–	P	–	–	–	–	–	–	2	1.0
01669520	Dragon Swamp at Mascot, VA	P	–	–	–	–	–	–	–	–	–	1	1.0
01670400	North Anna River near Partlow, VA	–	–	G	–	–	G	G	–	–	–	3	3.0
01671020	North Anna River at Hart Corner near Doswell, VA	–	–	–	F	–	–	–	–	–	–	1	2.0
01671025	North Anna River above Little River near Doswell, VA	P	–	F	–	–	F	G	–	F	–	5	2.0
01671100	Little River near Doswell, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
01672500	South Anna River near Ashland, VA	–	–	G	–	–	G	G	–	G	–	4	3.0
01673000	Pamunkey River near Hanover, VA	–	–	G	–	–	G	F	–	G	–	4	2.8
01673550	Totopotomoy Creek near Studley, VA	P	–	–	P	–	–	–	–	–	–	2	1.0
01673800	Po River near Spotsylvania, VA	P	–	–	G	–	–	–	–	–	–	2	2.0
01674000	Mattaponi River near Bowling Green, VA	–	–	G	G	–	G	–	–	G	–	4	3.0
01674500	Mattaponi River near Beulahville, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
02011400	Jackson River near Bacova, VA	–	–	G	E	–	–	–	–	–	–	2	3.5
02011460	Back Creek near Sunrise, VA	–	–	–	E	–	–	–	–	–	–	1	4.0
02011470	Back Creek at Sunrise, VA	–	–	–	E	–	–	–	–	–	–	1	4.0
02011490	Little Back Creek near Sunrise, VA	–	–	–	E	–	–	–	–	–	–	1	4.0
02011500	Back Creek near Mountain Grove, VA	–	–	–	E	–	–	–	–	–	–	1	4.0
02011800	Jackson River below Gathright Dam near Hot Spgs, VA	–	–	–	E	–	–	–	–	–	–	1	4.0
02013000	Dunlap Creek near Covington, VA	–	–	–	G	–	–	–	–	–	–	1	3.0
02013100	Jackson River below Dunlap Creek at Covington, VA	–	–	–	G	–	–	–	–	–	–	1	3.0
02014000	Potts Creek near Covington, VA	–	–	–	G	–	–	–	–	–	–	1	3.0
02015700	Bullpasture River at Williamsville, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02016000	Cowpasture River near Clifton Forge, VA	–	G	–	E	–	–	–	–	–	–	2	3.5
02016500	James River at Lick Run, VA	–	G	–	E	–	–	–	–	–	–	2	3.5
02017500	Johns Creek at New Castle, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02018000	Craig Creek at Parr, VA	–	G	–	G	–	–	–	–	–	–	2	3.0
02018500	Catawba Creek near Catawba, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02019500	James River at Buchanan, VA	–	G	–	E	–	–	–	–	–	–	2	3.5
02020500	Calfpasture River above Mill Creek at Goshen, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02021500	Maury River at Rockbridge Baths, VA	–	G	G	E	–	–	–	–	G	–	4	3.3
02022500	Kerrs Creek near Lexington, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
02024000	Maury River near Buena Vista, VA	–	G	F	G	–	–	–	–	G	–	4	2.8
02024752	James River at Blue Ridge Pkwy near Big Island, VA	G	–	P	G	–	–	–	–	–	–	3	2.3
02024915	Pedlar River at Forest Road near Buena Vista, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02025500	James River at Holcomb Rock, VA	–	F	F	E	–	–	–	–	G	–	4	2.8
02026000	James River at Bent Creek, VA	–	F	G	E	–	–	–	–	G	–	4	3.0
02027000	Tye River near Lovingston, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02027500	Piney River at Piney River, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02028500	Rockfish River near Greenfield, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02029000	James River at Scottsville, VA	–	–	G	E	–	E	G	–	G	–	5	3.4

Table 22.   Control and rating stability assessments made by senior hydrographers in the Virginia Water Science Center and Virginia Department of Environmental Quality for streamgages in Virginia active September 30, 2013.—Continued

[–, no response; E, excellent; G, good; F, fair; P, poor. Averages were computed by assigning numeric equivalents of 4 for excellent, 3 for good, 2 for fair, and 1 for poor. *Italicized* sites were not characterized by any hydrographer in response to questionnaires and were assigned scores by the authors from other descriptions. Individual hydrographers are identified by number, chronologically in the order that questionnaires were received; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Hydrographer										Number of replies	Average stability score
		1	2	3	4	5	6	7	8	9	10		
02030000	Hardware River below Briery Run near Scottsville, VA	P	–	–	G	–	–	–	–	–	–	2	2.0
02030500	Slate River near Arvonia, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02031000	Mechums River near White Hall, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02032250	Moormans River near Free Union, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02032640	North Fork Rivanna River near Earlysville, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02034000	Rivanna River at Palmyra, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02035000	James River at Cartersville, VA	–	–	G	–	–	E	G	–	E	–	4	3.5
02036500	Fine Creek at Fine Creek Mills, VA	F	–	–	E	–	–	–	–	–	–	2	3.0
02037000	James River And Kanawha Canal near Richmond, VA	P	–	–	G	–	–	–	–	–	–	2	2.0
02037500	James River near Richmond, VA	G	–	–	E	–	–	–	–	–	–	2	3.5
02038850	Holiday Creek near Andersonville, VA	–	–	F	–	–	–	G	–	G	–	3	2.7
02039000	Buffalo Creek near Hampden Sydney, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
02039500	Appomattox River at Farmville, VA	–	–	G	G	–	G	G	–	G	–	5	3.0
02040000	Appomattox River at Mattoax, VA	P	–	–	F	–	–	–	–	–	–	2	1.5
02040892	Appomattox River at Route 602 near Mannboro, VA	–	–	G	–	–	G	G	–	G	–	4	3.0
02041000	Deep Creek near Mannboro, VA	P	–	–	F	–	–	–	–	–	–	2	1.5
02041650	Appomattox River at Matoaca, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02042500	Chickahominy River near Providence Forge, VA	–	–	E	–	–	G	G	–	G	–	4	3.3
02044500	Nottoway River near Rawlings, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02045500	Nottoway River near Stony Creek, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02046000	Stony Creek near Dinwiddie, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02047000	Nottoway River near Sebrell, VA	–	–	F	–	–	G	–	–	G	–	3	2.7
02047500	Blackwater River near Dendron, VA	P	–	–	–	–	–	–	–	–	–	1	1.0
02049500	Blackwater River near Franklin, VA	–	–	P	–	–	P	–	–	F	–	3	1.3
02051000	North Meherrin River near Lunenburg, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02051500	Meherrin River near Lawrenceville, VA	–	–	G	–	–	G	–	–	F	–	3	2.7
02052000	Meherrin River at Emporia, VA	P	–	–	F	–	–	–	–	–	–	2	1.5
02053800	South Fork Roanoke River near Shawsville, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02054500	Roanoke River at Lafayette, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02054530	Roanoke River at Glenvar, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02055000	Roanoke River at Roanoke, VA	–	G	–	G	–	–	–	–	–	–	2	3.0
02055100	Tinker Creek near Daleville, VA	–	–	–	G	–	–	–	–	–	–	1	3.0
02056000	Roanoke River at Niagara, VA	–	G	–	G	–	–	–	–	–	–	2	3.0
02056650	Back Creek near Dundee, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02056900	Blackwater River near Rocky Mount, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
02058400	Pigg River near Sandy Level, VA	–	–	P	–	–	F	–	–	G	–	3	2.0
02059485	*Goose Creek at Rt 747 near Bunker Hill, VA*	–	–	–	–	–	–	–	–	–	–	0	3.0
02059500	Goose Creek near Huddleston, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
02060500	Roanoke River at Altavista, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
02061000	*Big Otter River near Bedford, VA*	–	–	–	–	–	–	–	–	–	–	0	3.0
02061500	Big Otter River near Evington, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02062500	Roanoke (Staunton) River at Brookneal, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
02064000	Falling River near Naruna, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
02065500	Cub Creek at Phenix, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
02066000	Roanoke (Staunton) River at Randolph, VA	–	–	F	–	–	G	–	–	G	–	3	2.7

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Table 22.   Control and rating stability assessments made by senior hydrographers in the Virginia Water Science Center and Virginia Department of Environmental Quality for streamgages in Virginia active September 30, 2013.—Continued

[–, no response; E, excellent; G, good; F, fair; P, poor. Averages were computed by assigning numeric equivalents of 4 for excellent, 3 for good, 2 for fair, and 1 for poor. *Italicized* sites were not characterized by any hydrographer in response to questionnaires and were assigned scores by the authors from other descriptions. Individual hydrographers are identified by number, chronologically in the order that questionnaires were received; VA, Virginia; Rt, Route]

Streamgage number	Streamgage name	Hydrographer										Number of replies	Average stability score
		1	2	3	4	5	6	7	8	9	10		
02069700	South Mayo River near Nettleridge, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
02070000	North Mayo River near Spencer, VA	F	–	–	G	–	–	–	–	–	–	2	2.5
02071530	Smith River at Smith Riv Church near Woolwine, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
02072000	Smith River near Philpott, VA	–	–	G	–	–	E	–	–	G	–	3	3.3
02072500	Smith River at Bassett, VA	–	–	G	–	–	E	–	–	G	–	3	3.3
02073000	Smith River at Martinsville, VA	P	–	–	G	–	–	–	–	–	–	2	2.0
02074500	Sandy River near Danville, VA	G	–	–	G	–	–	–	–	–	–	2	3.0
02075045	Dan River at Stp near Danville, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
02075500	Dan River at Paces, VA	–	–	F	–	–	F	–	–	F	–	3	2.0
02077000	Banister River at Halifax, VA	–	–	G	–	–	G	–	–	G	–	3	3.0
02077500	Hyco River near Denniston, VA	–	–	P	–	–	–	–	–	G	–	2	2.0
02079640	Allen Creek near Boydton, VA	F	–	–	F	–	–	–	–	–	–	2	2.0
03164000	New River near Galax, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03165000	Chestnut Creek at Galax, VA	–	–	–	–	E	–	–	–	–	E	2	4.0
03165500	New River at Ivanhoe, VA	–	–	–	–	G	–	–	–	–	F	2	2.5
03167000	Reed Creek at Grahams Forge, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03168000	New River at Allisonia, VA	–	–	–	–	E	–	–	–	–	E	2	4.0
03170000	Little River at Graysontown, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03171000	New River at Radford, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03173000	Walker Creek at Bane, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03175500	Wolf Creek near Narrows, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03176500	New River at Glen Lyn, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03177710	Bluestone River at Falls Mills, VA	–	–	–	–	F	–	–	–	–	G	2	2.5
03207800	Levisa Fork at Big Rock, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03208500	Russell Fork at Haysi, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03208950	Cranes Nest River near Clintwood, VA	–	–	–	–	P	–	–	–	–	F	2	1.5
03209000	Pound River below Flannagan Dam, near Haysi, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03471500	South Fork Holston River at Riverside, near Chilhowie, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03473000	South Fork Holston River near Damascus, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03474000	Middle Fork Holston River at Seven Mile Ford, VA	–	–	–	–	E	–	–	–	–	E	2	4.0
03475000	Middle Fork Holston River near Meadowview, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03478400	Beaver Creek at Bristol, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03488000	North Fork Holston River near Saltville, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03490000	North Fork Holston River near Gate City, VA	–	–	–	–	F	–	–	–	–	F	2	2.0
03524000	Clinch River at Cleveland, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
03524500	Guest River at Coeburn, VA	–	–	–	–	F	–	–	–	–	G	2	2.5
03527000	Clinch River at Speers Ferry, VA	–	–	–	–	F	–	–	–	–	G	2	2.5
03529500	Powell River at Big Stone Gap, VA	–	–	–	–	F	–	–	–	–	F	2	2.0
03531500	Powell River near Jonesville, VA	–	–	–	–	G	–	–	–	–	G	2	3.0
Totals:	174	69	19	61	100	27	36	10	14	35	27	398	2.6

Appendix 1.   Plots for real-time streamgages in Virginia

A.   All available measurements

Three columns of plots for all real-time streamgages in Virginia active on September 30, 2013, with 20 or more flow measurements with positive flow values, organized by major river basin, with all available measurements for each site color coded by rating family showing (1) stage, flow, and a generalized additive model (GAM) curve. Appendix 1*A* depicts all available measurements for each plot, unlike appendix 1*B*, which groups measurements at each site by rating families. Rating families represent a series of measurements made during a period when a streamgage control was at relative equilibrium. For streamgages where more than one rating family was identified, they were numbered sequentially in chronological order as RF1, RF2, … RFn; non-sequential rating family numbers result from situations in which a rating family was omitted because its period of equilibrium did not last long enough for a sufficient number of measurements to be made to allow a meaningful GAM to be developed. The coefficient of determination for the GAM curve, R^2, is a measure of the amount of variation in the stage-streamflow relation explained by the GAM; (2) residuals from the GAM curve by date (times series scale of graphs vary), with a LOESS smoother; and (3) residuals from the GAM curve by Julian date, with a LOESS smoother. Shaded areas represent the 99-percent confidence interval of the relevant curve.

B.   Measurements grouped by rating families

Three columns of plots for all real-time streamgages in Virginia active on September 30, 2013, with 20 or more flow measurements with positive flow values organized by major river basin, with all available measurements for each site, showing (1) stage, flow, and a generalized additive model (GAM) curve. Unlike appendix 1*A*, which depicts all available measurements for each plot, appendix 1*B* groups measurements at each site by rating families. Rating families represent a series of measurements made during a period when a streamgage control was at relative equilibrium. For streamgages where more than one rating family was identified, they were numbered sequentially in chronological order as RF1, RF2, … RFn; non-sequential rating family numbers result from situations in which a rating family was omitted because its period of equilibrium did not last long enough for a sufficient number of measurements to be made to allow a meaningful GAM to be developed. The coefficient of determination for the GAM curve, R^2, is a measure of the amount of variation in the stage-streamflow relation explained by the GAM; (2) residuals from the GAM curve by date, and (3) residuals from the GAM curve by Julian date. Shaded areas represent the 99-percent confidence interval of the relevant curve.

Appendix 1 is available online at https://doi.org/10.3133/sir20175137

Appendix 2. Computation of Alternative Flow (AltFlow) Data

Two primary datasets were used to develop the AltFlow tables, (1) daily flow values for 1990–2013 and (2) the compiled tables of expanded shifted ratings (Messinger and Burgholzer, 2017). Two ancillary datasets also were used. A table containing all flow measurements was retrieved from NWIS-Web (National Water Information System-Web) and used to identify dates on which those flow measurements were made. Daily flows (Q_{meas}) were retrieved from NWIS-Web. A table of all shifts was retrieved from the NWIS command-line interface and manually processed to identify the earliest dates for each streamgage for which shifts were stored in the database (table 2).

Columns in the AltFlow table that originated in the retrieval of daily flow values included station number (site_no), date, flow in cubic feet per second, and qualifier (Messinger and Burgholzer, 2017). Because dates in other files were formatted in multiple ways, date in the original MM/DD/YYYY format (month as a two-digit number, date as a two-digit number, and year as a four-digit number, with the three sets of numbers separated by slashes) was retained. Another column was created and populated with date in the YYYYMMDD format (year as a four-digit number, month as a two-digit number, and date as a two-digit number, with no separators of any type between the three sets of numbers).

For each streamgage, the earliest date when AltFlows could be computed was determined ("Valid Start Date"). This date was the earliest date for which both base ratings and shifts were available. Both shifts and ratings were assumed to be continuously available following this date. These dates were identified in a table developed from retrievals of ratings and shifts, and imported to this table using the Microsoft Excel VLOOKUP command with the site_no used for the lookup value. Once analysis and verification related to that table was final, the formulas were converted to values in order to reduce file size. All dates with values of Q_{meas} were compared to Valid Start Date for the relevant streamgage and flagged as to whether or not valid values for Q_{prev} and Q_{same} could potentially be computed for that date.

The column "Lookup" contains a unique identifier for streamgage-date combinations. It is of the format Q.site_no.yyyymmdd, where site_no is the 8- or 10-digit station number and yyyymmdd is the date. The column was populated by concatenating the letter "Q" and the two other values; the letter "Q" was used as the first character in order to prevent Excel, R, and other software from truncating the leading zero from the station number. Lookup was used in conjunction with the VLOOKUP and INDEX/MATCH commands to populate several columns in this table by importing values from other tables.

The column "Expanded rating code" contains the value from the Lookup column for the dates when a retrieval of the expanded shifted rating table was desired. These represent dates when a flow measurement was made. This column was developed in order to simplify filtering the table for

verification checks and to reduce the complexity of IF statements used elsewhere in the table. It was populated by using the VLOOKUP command to retrieve the same code from a table of flow measurements; for dates not represented in the other table, an error code was returned. This table of flow measurements was obtained from NWIS-Web, and the only manual processing step that needed to be done in order to use it to develop the column "Expanded rating code" was to concatenate the letter "Q" with the values for station numbers and dates into a new column. To prevent unintended changes to this column and to reduce file size, the column was converted to values, and the error codes were deleted.

The column "NewSite" describes whether each row represents the first row for a new site when the table is sorted by station number then by date. The column was developed in order to make the table simpler to filter and troubleshoot. This statement is dependent on the sort order of the table and requires that the table be sorted first by site_no and then by date in chronological order.

The column "Rating lookup code, Q_{same}" contains the lookup code for the appropriate expanded shifted rating to compute Q_{same}. It was populated using an IF statement that checks the previous two columns. If the column "Expanded rating code" contains a non-blank value, the statement returns that value. If the column "NewSite" indicates the site is new, it returns the value "No rating available" until the first rating is available. Otherwise, the statement copies the previous value in this column. Like the statement in the column "NewSite," this statement is dependent on the sort order of the table and requires that the table be sorted first by site_no, then chronologically. The statement was written to allow the inclusion of values from the period before valid expanded shifted ratings were available because of the iterative fashion in which this dataset was developed and to accommodate the possibility that the initial retrieval was incomplete and additional valid shifts might be located.

The column "Stage" contains a derived value for stage. It is the stage value corresponding to the flow value closest to Q_{meas} in the relevant expanded shifted rating. The column was populated through a reverse lookup from the rating tables using the INDEX, MATCH, and OFFSET commands. The value from "Rating lookup code, Q_{same}" was used to find the appropriate column in the table of ratings; then the stage value matching the closest discharge value to Q_{meas} from that column was returned. Although all possible values of stage appear in rating tables, not all possible values of flow appear. Daily mean flow is computed by averaging the unit values for flow observed on a particular day, so the value of Q_{meas} may be a number that does not appear on a rating table. If flow values and ratings are added to those in the files, the addresses in the INDEX-MATCH-OFFSET statement must be modified to accommodate them.

This issue of rounding and of rating tables lacking many possible values for Q_{meas} was the reason the column "Q_{same}"

was developed. The column "Q_{same}" gives the flow value corresponding to the Stage value in the relevant rating table. This was done to remove one source of error when comparing the changes in rating tables in effect from the time of one flow measurement to the next. A direct comparison between Q_{meas} and Q_{prev} often included differences in flow for the same value of Stage, even if the rating was unchanged. The column was populated through a lookup from the rating tables using the INDEX and MATCH commands. The value from "Rating lookup code, Q_{same}" was used to find the appropriate column in the table of ratings, then the flow value from that column on the row matching the value for Stage was returned. If flow values and ratings are added to those in the files, the addresses in the INDEX-MATCH-OFFSET statement must be modified to accommodate them.

The column "Rating lookup code, Q_{prev}" contains the lookup code for the appropriate expanded shifted rating to compute Q_{prev}, the flow value that would have been obtained had the expanded shifted rating in effect at the time of the previous flow measurement remained in effect. It was populated using an IF statement that checks "Expanded rating code" and "Rating Lookup Code, Q_{same}." If the column "Rating Lookup Code, Q_{same}" contains the value "No rating available," the statement returns that value. For values in that column that are not equal to values in the previous cell in that same column, it returns the value from that previous cell. Otherwise, the statement copies the value in this previous cell of its own column. Like the statements in the columns "NewSite" and "Rating Lookup Code, Q_{same}," this statement is dependent on the sort order of the table and requires that the table be sorted first by site_no, then chronologically.

The column "DifferenceQ_{same}" gives the difference between Q_{meas} and Q_{same}. It was obtained by subtracting Q_{same} from Q_{meas}. This column was developed for troubleshooting.

The column "Q_{prev}" gives the flow value that would have been obtained from the expanded shifted rating in effect at the time of the previous flow measurement, had it remained in effect. The column was populated through a lookup from the rating tables using the INDEX and MATCH commands. The value from "Rating lookup code, Q_{prev}" was used to find the appropriate column in the table of ratings, then the flow value from that column on the row matching the value for Stage was returned. Valid values for Q_{prev} became available once two flow measurements were made after the base ratings and shifts began to be stored in the database. For the period between the first and second flow measurements subsequent to shifts being stored in the database, values of Q_{same} are available, but values of Q_{prev} are not. If flow values and ratings are added to those in the files, the addresses in the INDEX-MATCH-OFFSET statement must be modified to accommodate them.

The column "DifferenceQ_{prev}" gives the difference between Q_{meas} and Q_{prev}. It was obtained by subtracting Q_{prev} from Q_{meas}. This column was developed for troubleshooting.

The column "Check for hiatus" checks for a hiatus in record. It was populated using an IF statement that, within the records for a given streamgage, checks whether successive values in the "Date" column are more than one day in magnitude; when they are, the row in question is flagged as representing a hiatus in record. For such records, the ratings in effect before the hiatus were judged to be unrepresentative of variation typical from one normally scheduled site visit to the next, and values of Q_{prev} were deleted for the period before two post-hiatus site visits had been made. One site, 01671025, North Anna River above Little River near Doswell, is a continuous station with a limited discharge computation range, and as a result, it had numerous breaks in record of one to several days that resulted in false positives for this IF statement. The column "Comments" contains comments, principally relating to a hiatus in record or other reason for values to have been deleted.

If a user of this spreadsheet wishes to update the AltFlow record as new data become available, that may be accomplished by using the following procedure.

1. Open the desired file and determine whether available computers will process the files in an acceptable manner. If not, consider editing historical ratings and daily values out of the files to speed processing times.

2. Retrieve the desired daily values from NWIS-Web and paste them to the bottom of the table that contains daily values from the same streamgages. Sort each table so that data are grouped first by site, and then chronologically.

3. Retrieve a table of flow measurements for the same period from NWIS-Web. Extract the station numbers and dates for each site visit.

4. Follow the procedure described above to obtain and format all the necessary expanded, shifted ratings. Append the additional ratings to the tables which contain ratings from the same streamgages.

5. Modify the INDEX-MATCH and INDEX-MATCH-OFFSET commands in the flow tables so that they include the entire updated range of values in the rating tables.

6. Copy the formulas in the flow tables to the blank cells in the rows that have been added. Compute the AltFlows.

7. If desired, copy the AltFlows as values to a separate, smaller file for further analysis.

References Cited

Messinger, Terence, and Burgholzer, R.W., 2017, Ratings and estimated provisional streamflow for streamgages in Virginia, water years 1991 through 2013: U.S. Geological Survey data release, https://doi.org/10.5066/F72R3PXB.

Appendix 3.   UNIX shell scripts used to develop AltFlow record

This software has been approved for release by the U.S. Geological Survey (USGS). Although the software has been subjected to rigorous review, the USGS reserves the right to update the software as needed pursuant to further analysis and review. No warranty, expressed or implied, is made by the USGS or the U.S. Government as to the functionality of the software and related material nor shall the fact of release constitute any such warranty. Furthermore, the software is released on condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from its authorized or unauthorized use.

Appendix 3 is a spreadsheet with multiple tabs/worksheets, which contain short UNIX scripts, or Excel formulas that may be used to produce one-line UNIX scripts, to perform some of the data manipulation involved in converting expanded, shifted ratings retrieved from the National Water Information System as separate files to a joined table of the type in appendix 2, with gage height in the left column and one column for each expanded, shifted rating. They have been tested in the ksh shell under Solaris Unix version SunOS 5.10. Although these scripts may work on computers running other shells or under other UNIX and UNIX-like operating systems, they have not been tested in other environments.

Appendix 3 is available online at https://doi.org/10.3133/sir20175137

Appendix 4.   Plots showing daily time series of Q_{same} and Q_{prev}

A.   For the North Atlantic Slope Basins

Plots showing daily time series of Q_{same} (the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value) and Q_{prev} (the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value) and dates when flow measurements were made for all real-time streamgages in Virginia active on September 30, 2013, with 20 or more flow measurements with positive flow values, for the North Atlantic Slope Basins. Flows are shown as $\log_{10}$ of the actual flows, and negative values reflect daily flows that were less than 1 cubic foot per second. Erratic and abrupt changes in Q_{prev} result from relatively large, sudden changes in ratings.

B.   For the South Atlantic Slope Basins

Plots showing daily time series of Q_{same} (the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value) and Q_{prev} (the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value) and dates when flow measurements were made for all real-time streamgages in Virginia active on September 30, 2013, with 20 or more flow measurements with positive flow values, for the South Atlantic Slope Basins. Flows are shown as $\log_{10}$ of the actual flows, and negative values reflect daily flows that were less than 1 cubic foot per second. Erratic and abrupt changes in Q_{prev} result from relatively large, sudden changes in ratings.

C.   For the Ohio River Basin

Plots showing daily time series of Q_{same} (the flow value from the shifted rating table used to compute the daily flow value at the time of the most recent flow measurement that corresponds to the gage height of each day's daily flow value) and Q_{prev} (the flow value from the shifted rating table in effect at the time of the previous flow measurement that corresponds to the gage height of each day's daily flow value) and dates when flow measurements were made for all real-time streamgages in Virginia active on September 30, 2013, with 20 or more flow measurements with positive flow values, for the Ohio River Basin. Flows are shown as $\log_{10}$ of the streamflow in cubic feet per second, and negative values result from daily flows that were less than 1 cubic foot per second. Erratic and abrupt changes in Q_{prev} reflect relatively large, sudden changes in ratings.

Appendix 4 is available online at https://doi.org/10.3133/sir20175137

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