



Quality Assurance Monitoring Plan Washington State Streamflow Monitoring Program

By

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For the

Environmental Assessment Program

Washington State Department of Ecology

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Monitoring activities conducted by the Washington State Department of Ecology must have an approved Quality Assurance Monitoring Plan (QAMP). The plan describes the objectives of the monitoring program and the procedures to be followed to achieve those objectives. The Washington State Streamflow Monitoring Program is an on-going activity. Streamflow data are reported continuously and published annually.

This QAPP was approved to begin work in August 2025. It was finalized and approved for publication in October 2026.

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Data for this project are currently available on Ecology's [Freshwater DataStream](#). In the future, data will also be available in Ecology's [EIM Database](#) (Search Study ID: FMUFLOW&WQ).

The Activity Tracker Code for this study is 01-700.

Federal Clean Water Act 1996 303(d) Listings Addressed in this Study. See Section 3.3.

COVER PHOTO: Streamflow monitoring station on Morse Creek below Aqueduct (18C150), near Port Angeles. Photo by Tyler Burks

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Northwest Region
206-594-0000

Central Region
509-575-2490

Eastern Region
509-329-3400

Region	Counties Served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 47600 Olympia, WA 98504	360-407-6000

Quality Assurance Monitoring Plan Washington State Streamflow Monitoring Program

By James R. Shedd and Tyler W. Burks
October 2026

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EAP: Environmental Assessment Program

WOS: Western Operations Section

EOS: Eastern Operations Section

FMU: Freshwater Monitoring Unit

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2.0 Abstract

The Washington State Department of Ecology's (Ecology) Environmental Assessment Program (EAP) operates a statewide streamflow monitoring network that has provided continuous and credible streamflow data since 1996. The monitoring program is operated and managed by EAP's Freshwater Monitoring Unit (FMU). These data are publicly available and used by offices and programs within Ecology (Office of Columbia River, Office of Chehalis Basin, Water Resources and Water Quality Programs), other state agencies, Tribal and local governments, consulting firms, academia, recreationists, and other watershed interest groups. These data are used to assess current streamflow conditions, evaluate long-term trends, and establish historical baselines for inclusion in future research. The data are readily accessible in near-real time through the FMU's [Freshwater DataStream](https://apps.ecology.wa.gov/continuousflowandwq/).¹

This Quality Assurance Monitoring Plan (QAMP) documents procedures used by Ecology's staff in the FMU to address quality considerations associated with the collection, processing, storage, analysis, and publication of continuous streamflow records.

3.0 Background

3.1 Introduction and problem statement

The Freshwater Monitoring Unit (FMU) is a specialized program dedicated to the long-term monitoring of water quality and streamflow in rivers and streams across the state. Its primary goal is to collect, analyze, and report scientifically robust data to support water resource management, environmental protection, and policy development.

The FMU's streamflow monitoring group monitors water quantity in support of Ecology's mission of protecting and properly managing Washington's waters. Streamflow data collected and published through this monitoring program help to ensure adequate water resources for people and aquatic species to meet economic, agricultural, and community needs. By maintaining a long-term dataset, the FMU plays a critical role in understanding environmental change, guiding restoration efforts, and ensuring sustainable water management for future generations.

The FMU operates through two regional teams based in Western Washington and Eastern Washington, enabling comprehensive statewide coverage and responsiveness to the distinct hydrological and ecological characteristics of each region. These teams coordinate to implement standardized monitoring protocols, maintain a network of monitoring stations, and ensure data consistency and quality across the state.

The streamflow monitoring program provides information to support various statewide planning and management efforts. Accurate and timely streamflow data are critical for

¹ <https://apps.ecology.wa.gov/continuousflowandwq/>

managing water resources, conducting total maximum daily load (TMDL) evaluations, and designing and implementing Washington's response to climate change. The program's data also support ambient freshwater monitoring studies, toxics fate and transport studies, and salmonid recovery efforts. Ecology's Water Resources Program uses FMU streamflow records to manage smaller streams and locations not monitored by the United States Geological Survey (USGS), and Ecology's Water Quality Program requires streamflow data to manage pollutant loading limits.

The complex management initiatives supported by the streamflow monitoring program now face the layered challenge of being carried out within a changing climate. Some of our records span a period long enough to assess the impacts of climate change on streamflow in Washington. It is important to continue streamflow monitoring so we can further develop records and establish baselines that inform management decisions addressing climate change.

Management of surface water in Washington State requires a streamflow measurement network capable of monitoring water diversions, minimum instream flows, and water availability across the state. Both Ecology and the USGS operate streamflow-gaging programs throughout the state, focused on providing basic data to support water management needs. The USGS gaging program generally focuses on larger rivers, while Ecology typically monitors smaller streams.

3.1.1 Streamflow monitoring program development

Before the mid-1990s, under a joint funding agreement, the USGS provided discharge information corresponding to Ecology's water quality sampling. However, due to the expansion of the Ambient Monitoring Program and the increasing costs of getting streamflow information from USGS, Ecology began measuring discharge. The FMU (previously named the Stream Hydrology Unit) was founded to meet this need.

In the following years, the FMU developed the necessary skills and equipment to measure streamflow on larger rivers and deployed electronic stage height measurement devices (e.g., submersible pressure transducers). At select sites around the state, the FMU installed data loggers to begin recording stage heights and collecting continuous data.

By 2001, the FMU was collecting streamflow information at 58 sites around the state in support of the Ambient Monitoring Program, various TMDL studies, and other Ecology projects with discharge components. Of the 58 streamflow monitoring stations, 27 had continuous stage recorders, of which two had near-real-time capabilities. The two near-real-time stations, Chumstick Creek near Leavenworth and Morse Creek near Port Angeles, transmitted continuous stage data over landline or cellular-based telephone service. The streamflow data derived from the transmitted stage records were presented on a 7-day hydrograph on Ecology's web pages.

The following year, 2002, the FMU received a large grant from the Bonneville Power Administration to install 24 near-real-time gages using the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellites (GOES) telemetry.

In addition, we collected streamflow information at approximately 20 stations with manual stage height gages (primarily staff gages). That same year, we purchased the Hydstra® data management system, significantly boosting data storage capacity, as well as data management capability and efficiency.

The number of monitoring stations grew steadily to a high of 130 telemetered gages in 2008. Funding cuts around 2010 resulted in a reduction in the number of gages in the monitoring program. At the time of this writing, the streamflow monitoring network consists of 68 telemetered gages.

In the subsequent years through the present, we continued to refine procedures and pursue technological advances to improve the consistency and reliability of our data. Several utilities were developed to assist with records development, such as the automated error assessment application. As acoustic Doppler technology continued to advance, we acquired newer instrumentation to stay current with these developments and improve the quality and reliability of our discharge measurements. Similarly, as stage measurement instrumentation technology improved, we were able to take advantage of upgrades to existing equipment. We acquired newer types of equipment, such as radar gages that allow us to measure stage without deploying infrastructure in the channel. We continued to align our procedures with USGS methods to improve our measurement and data acquisition capabilities.

Over nearly three decades of developing and improving our methods, equipment, and capabilities, we are well-positioned to support Ecology's mission with high-quality streamflow data. By making these data freely available online, these gages serve not only Ecology's mission and program initiatives, but also the interests of the public (e.g., recreation), other agencies, Tribes, and academic research. These public stakeholders express a unifying challenge that our program tries to address: managing resources for the betterment of the environment, society, and future generations within the context of a changing climate. Maintaining a credible, timely source of streamflow data builds a valuable historical record and is critical for supporting those making complex decisions now and in the future.

3.2 Study area and surroundings

The statewide network (Figure 1) includes 68 active gages in 23 of the 62 Water Resource Inventory Areas (WRIA). Forty-two gages are located west of the Cascade crest, and 26 are located east of the crest. FMU staff from the Department of Ecology Headquarters in Lacey, Washington, manage the gages in western Washington. FMU-affiliated staff from Ecology's Eastern Regional Office in Spokane and Central Regional Office in Union Gap manage the monitoring network in eastern Washington. The FMU also operates gages in support of various temporary water quality studies across the state. Because of the transient nature of these gages and their fluctuating numbers over time, only gages considered permanent are included in the following map and list of active gages.

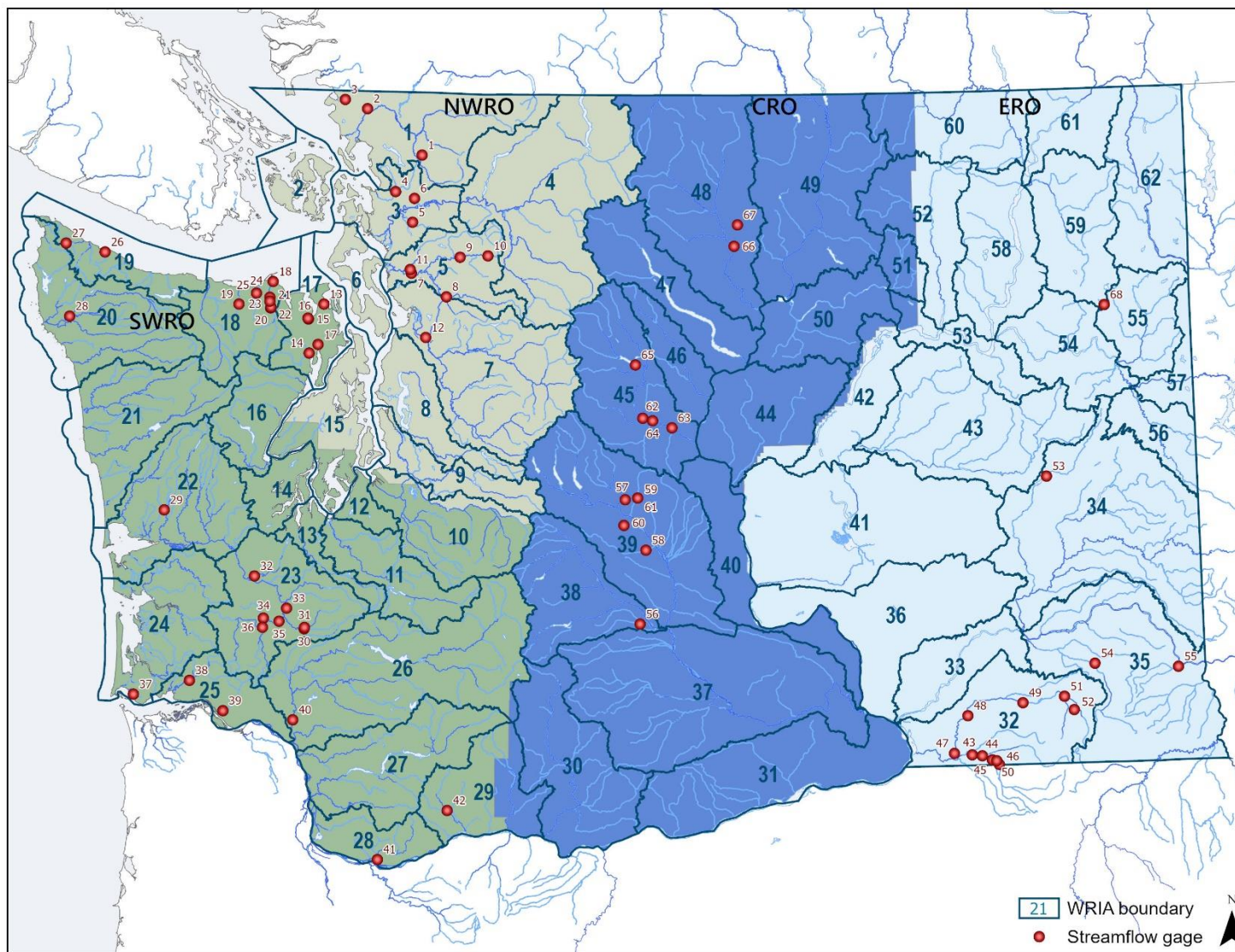


Figure 1. Map of active Environmental Assessment Program streamflow monitoring stations.

Table 1. List of active Environmental Assessment Program streamflow monitoring stations.

Map #	Station I.D. ^a	Station Name	Latitude ^b	Longitude ^b
1	01C070	Hutchinson Creek near Acme	48.723531	-122.155629
2	01N060	Bertrand Creek near mouth	48.924223	-122.530151
3	01Q070	Dakota Creek at Giles Road	48.962713	-122.682005
4	03C060	Friday Creek below Hatchery	48.558442	-122.328244
5	03G100	East Fork Nookachamps Creek at Beaver Lake Road	48.424037	-122.209892
6	03J100	Hansen Creek near Sedro-Woolley	48.530198	-122.200435
7	05A070	Stillaguamish River near Silvana	48.196782	-122.210067
8	05A105	South Fork Stillaguamish River at Jordan Road Bridge	48.095249	-121.974555
9	05B090	North Fork Stillaguamish River at Oso	48.272349	-121.887886
10	05B110	North Fork Stillaguamish River near Darrington	48.280286	-121.7025
11	05D070	Pilchuck Creek at Bridge 626	48.213474	-122.218518
12	07A090	Snohomish River at Snohomish PUD	47.91248001	-122.10647
13	17B050	Chimacum Creek at mouth	48.049771	-122.786289
14	17D060	Little Quilcene River near mouth	47.829861	-122.874978
15	17E060	Snow Creek at Washington Dept. of Fish and Wildlife	47.98139	-122.886381
16	17F050	Salmon Creek at Washington Dept. of Fish and Wildlife	47.985001	-122.890001

Map #	Station I.D. ^a	Station Name	Latitude ^b	Longitude ^b
17	17G060	Tarboo Creek near mouth	47.869511	-122.817537
18	18A050	Dungeness River near mouth	48.14340512	-123.1287309
19	18C150	Morse Creek below Aqueduct	48.037607	-123.35033
20	18F250	Agnew Irrigation Ditch near Sequim	48.02553353	-123.1394326
21	18H250	Sequim/Prairie Irrigation Ditch near Sequim	48.07255431	-123.1465573
22	18J250	Highland Irrigation Ditch near Sequim	48.02938904	-123.1373833
23	18K250	Independent Irrigation Ditch near Sequim	48.05544107	-123.1461145
24	18P070	McDonald Creek at Highway 101	48.089083	-123.236556
25	18R250	McDonald Irrigation Ditch at Diversion	48.08898032	-123.2364822
26	19H080	Clallam River near Clallam Bay	48.244361	-124.254444
27	19J100	North Fork Sekiu River near River Mile 2.4	48.2754557	-124.5166292
28	20A070	Sol Duc River near Quillayute	47.9514314	-124.4684975
29	22D110	Wishkah River near Nisson	47.10907	-123.789184
30	23B190	South Fork Newaukum River at North Fork Road	46.602464	-122.854103
31	23C070	North Fork Newaukum River at Forest Road	46.608405	-122.851763
32	23E060	Black River at Highway 12	46.830335	-123.186102
33	23H060	Salzer Creek at Airport Road	46.691534	-123.971318

Map #	Station I.D. ^a	Station Name	Latitude ^b	Longitude ^b
34	23I070	Bunker Creek at Ceres Hill Road	46.644199	-123.11923
35	23J070	Stearns Creek at Twin Oaks Road	46.632393	-123.017603
36	23K060	South Fork Chehalis River at Highway 6	46.60322	-123.1233
37	24N070	Chinook River at Chinook Valley Road	46.2835	-123.9375
38	25B060	Grays River at Covered Bridge	46.35510038	-123.5813624
39	25C060	Elochoman River at Monroe Drive	46.22572425	-123.3591125
40	26B080	Cowlitz River at Lexington	46.19544	-122.90943
41	28B080	Washougal River at Hathaway Park	45.58358565	-122.3456946
42	29C100	Wind River at Stabler	45.80844499	-121.9088076
43	32A090	Walla Walla River at McDonald Road	46.04823	-118.55497
44	32A100	Walla Walla River at East Detour Road	46.043083	-118.49075
45	32A105	Walla Walla River at Beet Road	46.02366	-118.42723
46	32A120	Walla Walla River at Pepper Bridge	46.00257	-118.38346
47	32B075	Touchet River at Cummins Road	46.0567	-118.66865
48	32B090	Touchet River at Luckenbill Road	46.22304	-118.57673
49	32B100	Touchet River at Bolles	46.274276	-118.22115

Map #	Station I.D. ^a	Station Name	Latitude ^b	Longitude ^b
50	32D060	Yellowhawk Creek near mouth	46.0193	-118.39949
51	32E050	North Fork Touchet River above Dayton	46.29762	-117.95306
52	32K070	Wolf Fork Touchet River at Mountain Home Park	46.23676	-117.89319
53	SPRAD1	Sprague Lake near Sprague	47.2798	-118.02494
54	35B150	Tucannon River near Marengo	46.44017	-117.75011
55	35K050	Alpowa Creek at mouth	46.412215	-117.213338
56	38G150	Cowiche Creek below Confluence	46.647241	-120.682154
57	39D110	Teanaway River at Red Bridge Road	47.200747	-120.78161
58	39J070	Manastash Creek at Cove Road	46.976067	-120.645532
59	39M130	Swauk Creek below First Creek	47.208325	-120.700369
60	39P080	Taneum Creek at Brain Ranch	47.086274	-120.78923
61	39S050	First Creek at mouth	47.208164	-120.699852
62	45B070	Icicle Creek near Leavenworth	47.563575	-120.6677
63	45E070	Mission Creek near Cashmere	47.521239	-120.475859
64	45F070	Peshastin Creek at Green Bridge Road	47.55232	-120.603097
65	45J070	Nason Creek near mouth	47.80083294	-120.7171238
66	48F060	Beaver Creek near mouth	48.32836	-120.061073
67	48F150	Beaver Creek below Lester Road	48.423504	-120.037477
68	LOOST1	Loon Lake at Granite Point	48.03434	-117.60614

Table 1 Note:^a Refer to Appendix A for a comprehensive list of complete website addresses that can be used to access each station directly on the Freshwater DataStream application.

^b Latitude and longitude coordinates are referenced to the WGS84 — World Geodetic System of 1984.

3.2.1 Hydroclimatology of study area

Climatically, Washington is divided into two distinct regions: the east and west sides of the Cascade Mountain range. The east side, characterized by a predominantly dry, semi-arid climate with distinctive warm summers and cool winters, contrasts significantly with the west side. The west side typifies a marine climate characterized by relatively dry summers and mild, wet winters, autumns, and springs. Several climatic controls dominate the region, namely, mountainous terrain (Cascades and Olympics), the Pacific Ocean, and semi-permanent high and low-pressure regions located over the North Pacific Ocean. The effects of these various controls combine to produce entirely different conditions within relatively short distances (NOAA 1985).

The discharge of rivers in Washington State, strongly influenced by rainfall patterns and the elevation of mountains feeding the rivers, is classified into three general categories described below (Elsner et al. 2009):

Rain-dominated: These small- to mid-size basins are at low elevations where most precipitation is in the form of rain. Streamflow peaks in winter due to periods of high precipitation. Summer streamflow is dominated by groundwater discharge from local aquifer systems. Groundwater supplies are recharged from rainfall from the fall through spring.

Transition, or mixed rain-snow: These are mid-elevation basins that may have winter snowpack but are also susceptible to rain-and-snow events or lack of snowpack in mild winters. Rivers in these watersheds usually peak twice annually from periods of high precipitation in winter and snowmelt in spring and summer. Late summer streamflow comes from groundwater discharge, typically from local aquifer systems. Groundwater sources are recharged from fall through spring rains or early summer snowmelt.

Snow-dominated: These basins have substantial high elevation areas with deep winter snowpack. Rivers with high-elevation watersheds tend to peak once annually in early summer from snowmelt. Snowmelt timing and changing glacial melt rates may affect summer streamflow. Groundwater recharge in these areas occurs in spring and summer from snowmelt in the headwaters and in fall through spring from rainfall and snowmelt in the mid and lower elevations. Most snow-dominated streams are located on the east side of the Cascade Range.

3.2.2 Summary of previous studies and existing data

Beginning in the late 1800s, motivated by the survey and assessment of irrigation potential in the arid West, the USGS started to develop equipment and a systematic approach to measuring streamflow (Gunn et al. 2014). During the ensuing 136 years, the USGS established itself as the primary source for real-time and historical streamflow information in the U.S., as well as the national standard for streamflow monitoring techniques and procedures. Though the [USGS](#)

[gaging network](#) is vast, the need remains for targeted monitoring efforts to address the needs of specific entities.²

While the USGS is the most prominent and operates the most gages around the state, several agencies and entities across Washington actively monitor streamflow and make their streamflow records available to the public. All these organizations have their own purposes for developing a streamflow monitoring program, and different timelines of creation. In addition to the USGS, some of these known entities include:

- [United States Bureau of Reclamation](#)³
- [King County](#)⁴
- [Pierce County](#)⁵
- [Snohomish County](#)⁶
- [Kitsap Public Utilities District](#)⁷
- [Thurston County](#)⁸
- [Walla Walla Basin Watershed Council](#)⁹

As was discussed in section 3.1, as early as the mid-1990s, Ecology and the Environmental Assessment Program identified the need to fill monitoring gaps for various scientific and regulatory purposes. Generally, streamflow information from a variety of smaller watersheds than those monitored by the USGS was needed.

All these streamflow monitoring programs are active and produce streamflow records for a specific local or regional purpose. Our role is to produce credible streamflow data at locations vital to Ecology's mission, while also supporting our local partners, the public, and contributing to the growing catalog of streamflow records across the state.

3.2.3 Parameters of interest and potential sources

The primary parameter of interest is streamflow, or discharge. Stream discharge is the volume of water in a stream or river per unit of time. Discharge values may be measured directly by a hydrologist on site or may be calculated using recorded stage values and an established rating curve.

² <https://dashboard.waterdata.usgs.gov/app/nwd/en/>

³ <https://www.usbr.gov/pn/hydromet/realtime.html>

⁴ <https://green2.kingcounty.gov/hydrology/Default.aspx>

⁵ <https://waterquality.piercecountywa.gov/applications/public.html?publicuser=Guest#waterdata/stationoverview>

⁶ <https://www.snohomishcountywa.gov/925/All-Real-Time-Gauges-by-Basin>

⁷ <http://kpudhydrodata.kpud.org/>

⁸ <https://www.thurstoncountywa.gov/departments/community-planning-and-economic-development-cped/community-planning/water-dashboard>

⁹ <https://www.wwbwc.org/index.php/monitoring>

Stage is defined as the water surface elevation, or the height of the water surface above a datum (Rantz et al. 1982). All streamflow gages in the statewide network record stage data, which may be used to develop either a discrete or continuous record of discharge. The combination of stage measurements, discharge measurements, and physical channel measurements over a broad range of streamflow conditions contributes to the development of the rating curve, which is then used to calculate the discharge time series for a given streamflow station.

Physical measurements required to calculate discharge include channel width and depth, elevation, and water velocity. The program uses standardized methods to measure these parameters as described in Sections 6.2, 7.2, and 8.2 of this document.

Most streamflow stations also record air and water temperature for the purpose of remotely confirming the presence of ice in the channel, which can impact continuous stage data. The original intent of monitoring air and water temperatures was to assess ambient on-site conditions. However, quality assurance protocols were not documented.

3.2.4 Regulatory criteria or standards

Ecology's Water Resources Program uses USGS and FMU streamflow monitoring program gages to regulate prior appropriation doctrine water rights (chapter 90.03 RCW), including trust water rights, and instream flow rules (chapter 173-500 through chapter 173-564 WAC) across the state. In addition, federally mandated water quality impairment studies, as well as fisheries management programs, utilize continuous records generated by this program.

The FMU complies with all laws and agreements with respect to the installation, operation, and access to streamflow monitoring stations. The streamflow gages are subject to federal, state, and local regulations, as well as terms of properly documented permits and permissions from affected landowners (private, federal, state, and local agencies).

The Washington Department of Fish and Wildlife requires a Hydraulic Project Approval (HPA) permit for all gages installed throughout the state. FMU staff renew the HPA every five years and report on station installations, repairs, and removals annually.

In addition, all gages are subject to and comply with the Washington Department of Labor and Industries regulations regarding codified electrical wiring and grounding of FMU electronic monitoring equipment.

The FMU Supervisor ensures all gages comply with applicable regulations. EAP section managers have signatory authority for all landowner agreements and permits.

4.0 Project Description

4.1 Project goals

The primary project goal of the streamflow monitoring program is to document current streamflow and lake level conditions of freshwater bodies in Washington State, while also building a historical baseline for future research and analysis of streamflow conditions across the state.

A secondary goal is to provide streamflow records for public consumption through Ecology's internet-based [Freshwater DataStream](https://apps.ecology.wa.gov/continuousflowandwq/)¹⁰ application. Potential consumers include state, federal, and Tribal agencies, educational institutions, the private sector, and interested citizens. These records provide streamflow information in support of internal agency and EAP initiatives such as assessing climate change, providing information for water resource management, and water quality projects.

4.2 Project objectives

The objectives of the streamflow monitoring program include:

- Develop reliable, accurate, and timely streamflow records.
- Publish provisional streamflow data in near real-time for access and use by Ecology programs, partner agencies, and public stakeholders, via the Freshwater DataStream.
- Publish finalized water year streamflow records and supporting technical note documents in a timely manner.
- Conduct regular discharge measurements at the full range of stage to verify and further develop stage-discharge rating curves at Freshwater Monitoring Unit's (FMU) statewide monitoring program stations.
- Ensure proper field data collection, post-processing, storage, analysis, review, and publication of surface water records by observing the policies, procedures, and standards set forth by the FMU in the QAMP, and the supporting Standard Operating Procedures (SOPs).
- Utilize modern, hydrology-specific software and database systems capable of storing, analyzing, reviewing, and publishing large volumes of continuous streamflow records.
- Conduct senior-level review of all records to ensure project objectives are attained in accordance with the QAMP and SOPs

¹⁰<https://apps.ecology.wa.gov/continuousflowandwq/>

- Continue to develop and improve surface water measurement methods and procedures based on established and novel protocols developed by the United States Geological Survey (USGS).
- Assess streamflow trends over time, at gages with a minimum of ten complete years of record.

4.3 Information needed and sources

The streamflow monitoring program generates ongoing, continuous streamflow records and will not require additional data sources to carry out most objectives throughout the gaging network. Existing data from recent and historical monitoring provide the baseline information needed for future streamflow analyses. Additional sites may be considered to meet future needs as identified by participating Ecology programs during the EAP annual planning process.

4.4 Tasks required

Ongoing tasks for the collection, review, and publication of near-real-time streamflow data across the state are underway and are described in detail throughout this document. Field and technical tasks required to meet project goals are described in Section 8.0.

4.5 Systematic planning process

This Quality Assurance Monitoring Plan addresses the elements of the systematic planning process.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2 shows the responsibilities of those who will be involved in this monitoring program.

Table 2. Organization of project staff and responsibilities.

Staff ^a	Title	Responsibilities
Jim Shedd Freshwater Monitoring Unit WOS Phone: 360-522-2885	Technical Coordinator and Senior Level Reviewer	Writes and updates the QAMP. Conducts quality analysis review of data, analyzes, and interprets data. Directs development and update of technical policy, quality analysis methods, and standard operating procedures (SOP). Authors and reviews SOPs. Manages senior level review process and reviews annual hydrologic records. Trains staff as needed in hydrologic methods and techniques.
Tyler Burks Freshwater Monitoring Unit WOS Phone: 360-764-3260	Senior Level Reviewer/Basin Lead/Technical Support	Assists with writing and updating the QAMP. Authors and reviews SOPs. Assists with development and updating of technical policy and quality analysis methods. Conducts senior level review of annual hydrologic records. Conducts Basin Lead duties. Provides secondary database and Freshwater DataStream reporting support.
Markus Von Prause Freshwater Monitoring Unit WOS Phone: 206-305-8179	Database Administrator and Telemetry Coordinator	Administers the streamflow data management platform. Ensures proper storage of streamflow record parameters. Manages integration of telemetered parameters with the data management platform and reporting to the Freshwater DataStream.
Mike Anderson Freshwater Monitoring Unit EOS Phone: 509-220-1347	Basin Lead	Ensures field data collection platforms (DCPs) are operating and telemetered DCPs are reporting reliable, near real-time streamflow data on the Freshwater DataStream. Conducts streamflow measurements following written protocols. Develops and maintains rating curves. Compiles annual hydrologic records for review.
Paul Anderson Freshwater Monitoring Unit WOS Phone: 360-338-2530	Basin Lead	Ensures field DCPs are operating and telemetered DCPs are reporting reliable, near real-time streamflow data on the Freshwater DataStream. Conducts streamflow measurements following written protocols. Develops and maintains rating curves. Compiles annual hydrologic records for review. SOP Author.

Staff^a	Title	Responsibilities
Andy Bookter Freshwater Monitoring Unit WOS Phone: 360-701-9672	Basin Lead	Ensures field DCPs are operating and telemetered DCPs are reporting reliable, near real-time streamflow data on the Freshwater DataStream. Conducts streamflow measurements following written protocols. Develops and maintains rating curves. Compiles annual hydrologic records for review. SOP Author.
Casey Clishe Freshwater Monitoring Unit WOS Phone: 360-485-5563	Basin Lead	Ensures field DCPs are operating and telemetered DCPs are reporting reliable, near real-time streamflow data on the Freshwater DataStream. Conducts streamflow measurements following written protocols. Develops and maintains rating curves. Compiles annual hydrologic records for review. SOP Author.
Mitch Wallace Freshwater Monitoring Unit EOS Phone: 509-828-7031	Basin Lead	Ensures field DCPs are operating and telemetered DCPs are reporting reliable, near real-time streamflow data on the Freshwater DataStream. Conducts streamflow measurements following written protocols. Develops and maintains rating curves. Compiles annual hydrologic records for review.
Kevin Royse Freshwater Monitoring Unit EOS Phone: 509-379-5787	Field Assistant	Provides field and streamflow measurement assistance to Eastern operations staff. Follows streamflow measurement protocols.
Michael Trunkhill Freshwater Monitoring Unit WOS Phone: 360-688-4091	Field Assistant	Provides field and streamflow measurement assistance to Western operations staff. Follows streamflow measurement protocols.
Ansel Abbett Freshwater Monitoring Unit WOS Phone: 360-688-4586	Engineering Technician	Gage network Infrastructure lead. Purchases, installs, maintains, and troubleshoots station infrastructure, data recording, and transmission equipment across the state.
Kevin Wood Freshwater Monitoring Unit WOS Phone: 360-764-6232	Engineering Technician	Gage network Infrastructure lead. Purchases, installs, maintains, and troubleshoots station infrastructure, data recording, and transmission equipment across the state.

Staff ^a	Title	Responsibilities
Thomas Jetson Freshwater Monitoring Unit WOS Phone: 564-669-1733	Unit Supervisor for Project Manager	Provides internal review of the QAMP, approves the budget, and approves the final QAMP. Directs and oversees all FMU activities. Ensures all Ecology and EAP policies and procedures are followed.
Jeremy H. Reiman WOS Phone: 564-699-0777	Section Manager for Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Scott Tarbutton EOS Phone: 509-867-6534	Section Manager for EOS	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Christina Frans Phone: 360-995-2473	Ecology Quality Assurance Officer	Reviews and approves the draft QAMP and the final QAMP.

^a All staff are from EAP

EAP: Environmental Assessment Program

EOS: Eastern Operations Section

FMU: Freshwater Monitoring Unit

QAMP: Quality Assurance Monitoring Plan

WOS: Western Operations Section

5.2 Special training and certifications

Personnel using this document will obtain the training necessary to operate hydrologic monitoring and measurement equipment. In addition, staff are trained in the use of data management platforms, software, and related utilities designed to develop streamflow records and present real-time discharge data on the internet. Upon appointment to a position with the streamflow monitoring program, staff undergo extensive and comprehensive training. Staff will have knowledge of the field and safety procedures associated with the collection of streamflow information. Users of this document typically work in the Environmental Specialist, Natural Resource Scientist, or Hydrogeologist job classifications. In-house documents describe training plans for Hydrogeologist 1, 2, and 3 positions serving the streamflow program. No special certifications are currently required.

5.3 Organization chart

Not Applicable — See Table 2.

5.4 Proposed project schedule

Tables 3 – 5 list key activities, due dates, and lead staff for this monitoring program.

Table 3. Schedule for completing field and infrastructure work.

Task	Due date	Lead staff
Field work	Ongoing at 6-week intervals	See Table 2 for responsible staff
Continuous and telemetered station infrastructure maintenance	Ongoing, as required for special projects	See Table 2 for responsible staff

Table 4. Schedule for data entry.

Task	Due date	Lead staff
Field data to Software Platform	3 weeks from field visit	See Table 2 for responsible staff
Provisional Quality Assurance	3 weeks from field visit	See Table 2 for responsible staff
Rating Curve Maintenance	4 weeks, or as required	See Table 2 for responsible staff

Table 5. Schedule for records and technical note finalization.

Task	Due date	Lead staff
Submission of provisional streamflow records.	One year from end of water year	Basin Lead
Finalization of streamflow records.	Three months after submission of records	Basin Lead/Senior Level Reviewer
Publication of technical notes.	One month after finalization of records	Basin Lead/Senior Level Reviewer
Submit final record of annual streamflow for archive.	One month after publication of technical notes.	Basin Lead/Senior Level Reviewer

5.5 Budget and funding

EAP manages a biennial budget to fund the monitoring program for personnel, field work, supplies, and monitoring equipment. Internal funding sources that support this monitoring program include:

- Ecology Environmental Assessment Program
- Ecology Water Resources Program
- Ecology Office of Chehalis Basin
- Ecology Office of Columbia River

Funding sources from outside Ecology to support requested streamflow monitoring projects include:

- Wahkiakum County
- Washington Department of Fish and Wildlife
- Cowlitz County
- Makah Tribe

6.0 Quality Objectives

6.1 Data quality objectives

The Streamflow Monitoring Program's three primary data quality objectives consist of the following:

- Minimize uncertainty in published rating curves such that the uncertainty of each rating curve does not exceed ten percent.
- Minimize uncertainty in water year stage records so it does not exceed five percent.
- Keep the combined uncertainty inherent in rating curves and stage records to under fifteen percent.

Calculations for rating curve uncertainty, stage record uncertainty, and the combined uncertainty are provided in Section 13. Uncertainty in the context of the three data quality objectives is expressed as a percentage representing ranges that define the reliability of the streamflow record and its two major components: the rating curve and stage record. These uncertainties result from the cumulation of inherent errors found in all aspects of developing streamflow records. The sources of these errors are found in measurement instrumentation inaccuracies, human errors, as well as random and systematic errors, among other sources. In the case of a single site visit, amidst sometimes adverse ambient conditions and complex channel hydraulics, there are many tasks executed and decisions made that may result in errors affecting the overall uncertainty of the streamflow record. As described throughout this document, the Freshwater Monitoring Unit (FMU) does its best to minimize or eliminate these sources of error, thereby reducing the uncertainty and improving the reliability of streamflow records.

6.1.1 Stage record uncertainty

The major sources of uncertainty in the stage record are instrument drift, gage index observation errors, and movement of gage indexes. The uncertainty in the stage record is the difference between the observed water surface height at the primary gage index (PGI) and the stage instrument reading at the corresponding time. If not corrected, this results in an inaccurate stage record.

Instrument drift at a gaging station is an undesired change in instrument output over time, not a function of real changes in water surface elevation. We assume most cases of instrument drift occur incrementally over time (Freeman et al. 2004). This assumption holds that the least amount of drift occurs at the start of the data set or the initial calibration, when the logger and PGI match. The drift progresses over time until reaching the next calibration point, when the amount of drift is presumed to be greatest (Ecology 2022d). Stage records are corrected for instrument drift following the same assumption that the drift occurred incrementally over time between gage index observations; thus, corrections are made incrementally as well. In these cases, the type of drift we are correcting is considered random drift, characterized by

contiguous differences across the stage record and gage index observations that are not consistent in their magnitude. The contiguous differences between individual points in the stage record and corresponding gage-height observations do not form a linear relationship.

The type of drift where the differences between true gage heights and instrument outputs change linearly over time is called sensitivity drift. Sensitivity drift exhibits a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases or decreases, with a strong correlation between corrected stage and data shift correction values (Ecology 2022d).

Gage indexes are used to confirm stage measured by the stage sensor, which is logged and displayed at the station data. Errors in gage index observations can cause uncertainty in the stage record because adjustments to the record are based on errant gage index observations. Gage indexes include staff gages, wire-weight gages, laser level pads, and tape-down reference points. Multiple gage indexes may confirm or expose inaccuracies in the gage heights observed or measured from the other gage indexes. All gage index elevation values are relative to the gage datum and should match the same observed water surface elevations of the other gage indexes. Sometimes observations of water surface elevation between gage indexes may not match. This can be caused by simple observation errors of a gage index, or by biases from the streamflow conditions. Streamflow conditions that may bias a stage measurement include wave action, water surface bounce, and wind. High vertical distance from the gage index (wire weight or tape-down) location to the water surface may contribute to observation uncertainty. Occasionally, because of the site configuration, the observation of a gage index (laser level and staff) could be a long sight distance, which could introduce uncertainty.

Another source of uncertainty in the stage record is caused by the unexpected movement of established gage indexes. Since we use gage index observations to establish the stage on the logger, and as the basis from which we correct the stage record, any movement of the gage indexes could result in errant stage recordings and corrections. Observed differences between the gage indexes greater than 0.02 feet should be investigated by the basin lead. Confirming movement of a gage index may require running levels (determining vertical elevation differences using surveying equipment) to determine and mitigate vertical movement of gage indexes. The threshold for the confirmed vertical movement of the PGI, triggering adjustment to streamflow records, is 0.015 feet (Mastin 2017).

6.1.2 Rating curve uncertainty

We define the uncertainty in a rating curve as the percent difference between a measured discharge and the discharge predicted by the rating curve. This uncertainty includes a quality percentage applied to the discharge measurement representing the difference between the true discharge and the measured discharge. The quality assignment of the discharge measurement is determined by the basin lead and is based on streamflow conditions, channel characteristics, discharge instrument quality analysis feedback, and other criteria presented by Ecology (2021b).

6.2 Measurement quality objectives

In order to meet the three primary quality objectives defined above, the program has selected equipment and methods that minimize sources of uncertainty and allow for quantification and correction of common biases.

Streamflow data are based on field observations and measurements. While there is no reference standard for streamflow data, errors and uncertainties in the measurements can be evaluated and controlled (Mastin 2017). We have established measurement quality objectives and lowest acceptable thresholds in accordance with United States Geological Survey (USGS) protocols. We acquire equipment that can meet the lower limit of our established thresholds. Table 6 below defines the resolution and targeted lowest thresholds for parameters associated with discharge measurements.

Table 6. Measurement Quality Objectives- Discharge Measurements.

Parameter	Equipment/Method	Manufacturer Accuracy/ Resolution	Observer Resolution	Equipment Range	Targeted Lowest Threshold
Velocity— ADV^a	SonTek FlowTracker2	1% of measured velocity/0.0003 ft/s	N/A	0.003–13 ft/s	0.10 ft/s
Velocity— ADCP^b	TRDI RiverPro/StreamPro	0.25% of measured velocity/0.003 ft/s	N/A	0.01–16.4 ft/s	0.30 ft/s
Width— ADV	Measuring Tape	0.01 ft	0.10 ft	0–300 ft	0.30 ft
Depth	Wading Rod	0.10 ft	0.01 ft	0–4.0 ft	0.20 ft
Depth/Bottom Tracking	ADCP	1%/0.003 ft	N/A	0.50ft–115 ft	0.70 ft
Discharge	Duplicate Measurement	N/A	N/A	Site Specific	5%

^a ADV- Acoustic Doppler Velocimeter

^b ADCP- Acoustic Doppler Current Profiler

Table 7 below defines the resolution and targeted lowest thresholds for the electronic sensors logging stage and the physical observation of a gage height index.

Table 7. Measurement Quality Objectives- Stage logging and gage height index observation in the field.

Parameter	Equipment/Method	Equipment Resolution	Equipment Range	Targeted Lowest Threshold
Stage	Sutron: Compact Constant Flow Bubbler	0.05% reading with minimum of 0.01 ft	0–57 ft	0.01 ft or 0.2% of effective stage
Stage	WaterLog: H-3553 Bubbler	0.007 ft	0–34.60 ft	0.01 ft or 0.2% of effective stage
Stage	Radar: FTS SDI-Radar-64	0.003 ft	0–98.43 ft	0.01 ft or 0.2% of effective stage
Stage	WaterLog: H-310 Pressure Transducer	0.007 ft or 0.02% of effective stage	0–34.60 ft	0.01 ft or 0.2% of effective stage
Gage Height	Staff Gage	0.02 ft	3.33 ft sections (site specific)	0.01 ft
Gage Height	Laser Level Stadia Rod	0.01 ft	0-20 ft (datum relative)	0.01 ft
Gage Height	Wire Weight Gage	0.01 ft	Site Specific	0.01 ft
Gage Height	Crest Stage Gage	0.01 ft on Measuring Tape	0–4.0 ft (datum relative)	0.10 ft
Gage Height	Tape-Down	0.01 ft	0-50 ft	0.01 ft
Gage Height	Slant Gage	0.02 ft	3.33 ft sections (site specific)	0.01 ft
Gage Height—Index Discrepancy	Station Gage Indexes	0.02 ft observed	N/A	0.015 ft determined by levels

Parameter	Equipment/Method	Equipment Resolution	Equipment Range	Targeted Lowest Threshold
Gage Height— Point of Zero Flow	Wading Rod	0.10 ft	0–4 ft	0.10 ft

6.2.1 Minimizing errors and uncertainty

The Streamflow Monitoring Program uses many techniques and utilities to minimize error and uncertainty in continuous streamflow records. The following sections identify sources of uncertainty in the streamflow monitoring process and the methods we use to minimize them. These sources of uncertainty include the categories of precision, bias, and sensitivity.

6.2.1.1 Precision

Precision is a measure of the variability in the results of multiple measurements and observations. Precision does not imply accuracy but is a measure of the consistency of results and is affected by random errors, causing variability in measurements or observations. Monitoring program staff address precision in field observations and measurements in the following ways.

6.2.1.1.1 Precision of gage index observations

Multiple gage index observations associated with discharge measurements serve as a measure of precision. These observations, derived from multiple indexes, offer diverse sources of stage determination. Gage indexes are read and noted to the 0.01 ft. resolution. We observe each gage index at least twice when measuring discharge, once prior to the measurement and at the measurement conclusion. In circumstances when stage is fluctuating or suspected of fluctuating over the course of a measurement, additional gage height observations are conducted during the measurement.

In circumstances when stage is fluctuating rapidly, non-uniformly, or by more than 0.1 feet, we calculate a weighted mean gage height. To accomplish this, we use two separate computation methods, which are described in the document SOP EAP056 *Measuring and Calculating Stream Discharge* (Ecology 2021b).

6.2.1.1.2 Precision of logger stage samples

Most loggers deployed by the monitoring program use ten-second averaging. The logger collects stage measurements for ten seconds and then averages the measurements collected over the ten-second period. Most of the data loggers used by the program scan and record stage at 15-minute intervals (Ecology 2022a). At the time of this writing, we use data loggers from two manufacturers: Design Analysis/WaterLog®, and Sutron/Ott HydroMet® (Ecology 2024b). Both manufacturers produce loggers capable of user-defined average sampling times.

6.2.1.1.3 Precision of discharge measurements

The precision of Acoustic Doppler Current Profiler (ADCP) measurements is assessed using multiple measured transects to minimize the effect of random errors in measurement values. The total measurement duration of all transects must be at least 12 minutes. Each transect is essentially an individual discharge measurement. At the conclusion of the measurement, the measured transects are reviewed at the site. ADCP measurement post-processing systems calculate the standard deviation and coefficient of variation for mean discharge, velocity, area, and width. These statistics are considered when assessing the quality of a measurement. Any identified problems are assessed and, if necessary, individual transects are remeasured. If an entire measurement is compromised, a new measurement location is found, or an alternative deployment method is executed.

Monitoring program staff use SonTek FlowTracker (version 1 and 2) Acoustic Doppler Velocimeters (ADV) in standard wading discharge measurements. An ADV directly measures the point velocity of water in a stream. The total discharge is the sum of discharge in approximately 30 separate cells where measurements of depth and velocity are made. These measurements are collected at regular intervals across a stream cross-section. Precision is addressed by measuring multiple samples of each velocity recorded by the instrument. Each recorded velocity consists of a measurement time of 40 seconds. The ADV measures two individual velocities per second, resulting in a total of 80 velocity samples for each vertical. That is a total of approximately 2,400 velocity samples in a typical measurement. Standard error statistics are calculated by the ADV software for each recorded velocity. If the recorded velocity standard error is exceeded by 0.033 feet per second, a quality control warning is noted in the software output (Ecology 2021a).

Another approach to measuring the precision of discharge measurements is to conduct duplicates. This also serves as a tool to evaluate the techniques used to measure discharge. Each month, one randomly selected basin lead conducts a duplicate discharge measurement at a station for which they are responsible. The station will be randomly selected. Both discharge measurements will be considered “official,” and the records of both will be entered into the appropriate databases.

All duplicate measurements are treated as separate and discrete. All instrument setups and pre-measurement tests described in each instrument’s standard operating procedure are repeated prior to the second measurement.

The same cross-section and verticals (measurement points) are used for both measurements when conducting conventional wading measurements. The same cross-section and beginning bank are used for both measurements when collecting ADCP measurements. If, during the measurement, a stage change resulting in a change in discharge of greater than two percent occurs, then a second measurement is not conducted. Our aim is to measure the same discharge under the same channel conditions. We refer to the rating curve effective at the time of the measurement to determine the percentage of changes in discharge as stage fluctuates.

The objective of duplicating measurements is to document the random variability inherent in the measurement procedure when using the same instrument. The relative percent difference (RPD) is calculated and compared to the measurement quality objective of 5%. In addition, the cross-sectional areas and the average velocities of the two measurements should fall within five percent. The following formula is used to evaluate duplicate measurements:

$$RPD = \left[\frac{|R1 - R2|}{\frac{R1 + R2}{2}} \right] \times 100$$

Where:

R1=Result for the first measurement

R2=Result for the second measurement.

6.2.1.2 Bias

Bias in the context of streamflow monitoring refers to inaccuracies caused by systematic errors in the discharge record derived from data collection, analytical, and record development errors; all consisting of multiple components, each with their own sources of uncertainty.

6.2.1.2.1 Bias in wading discharge measurements

We recognize potential biases in point velocity measurements and take steps to account for these biases. These potential biases can arise from channel and hydraulic conditions influencing the assumption that the velocity measured at single points in the water column represents the velocity throughout the measurement vertical. Further sources of potential bias to point velocity measurements from an ADV sensor include inaccurate internal water temperature, physical geometry of the sensor, and the ability of the ADV sensor to collect reliable data in the measurement environment.

We attempt to minimize potential biases in velocity measurements in the following ways: In water depths less than 1.5 feet, we use the six-tenths method. Using ADVs or mechanical velocity meters, we measure velocity at 0.6 of the depth (from the water surface) and assume the measured velocity represents the average through the water column (Rantz 1982).

At depths greater than 1.5 feet, the two-point method is used. The two-point method consists of measuring velocities at 0.2 and 0.8 of the depth. The average of these two measurements determines the assumed velocity of the water column. When measuring from a bridge, cableway, or boat, the two-point method is used at depths greater than or equal to 2.5 feet.

The two-point method assumes a logarithmic relationship between strata of velocities through the water column. Generally, a logarithmic relation exists when velocities near the stream bottom are slower than velocities near the top of the water column. A non-logarithmic relation is identified when the two-tenths velocity is less than that of the eight-tenths, or the two-tenths velocity is greater than two times the eight-tenths velocity.

In circumstances where a non-logarithmic velocity condition exists, we use the three-point method. The three-point method consists of velocity samples at 0.2, 0.6, and 0.8 of the depth. To calculate the average velocity for non-logarithmic verticals, we calculate the average of the 0.6 velocity sample against the mean of the 0.8 and 0.2 velocity samples, thus weighting the 0.6 sample as half of the calculated velocity for the vertical (Rantz 1982; Ecology 2021b).

The biases in depth measurements are minimized by selecting cross-sections with minimal turbulence, ripples, and wave action. We look for smooth channel bottoms and consistent depths through the cross-section. Many factors can bias depth measurements when measuring streamflow, including streambed roughness and variability, water surface variations from turbulence, and velocity head buildup on the wading rod. These conditions can impact the accuracy of the depth measurement. The effect of errors in depth measurements as a percentage of cross-sectional area diminishes as the water becomes deeper.

Operation of an ADV requires pre-measurement diagnostics both in the office and measurement environment to verify proper system function and to identify potential sensor bias. The ADV sensor geometry is calibrated during manufacture and, due to its rigid construction, does not require periodic recalibration unless the sensor is physically damaged (SonTek/Xylem, Inc. 2024).

Beam Check is a SonTek diagnostic tool used to test and track the integrity of the ADV sensor in a controlled environment before the unit is deployed for regular use in the field. A Beam Check is required when (1) a new instrument is received, (2) if physical damage (e.g., dropping) may have occurred, (3) a firmware upgrade or repair is made, and (4) after any Automated Beam Check failures that cannot be explained by improper placement in the measurement environment (Ecology 2021a)

The Automated Beam Check procedure is required to be completed in the field before each discharge measurement is started, to ensure system function and that the measurement conditions are adequate for sensor use (Ecology 2021a), such as sufficient suspended particles in the water column for reflection of sound waves transmitted by the sensor.

Water temperature measurements are used by the ADV's software to remove the speed of sound bias from velocity measurements. Erroneous water temperatures from the ADV's internal temperature sensor can introduce error into the determination of stream velocities. A 5°C error in temperature would result in a $\approx 2\%$ error in mean velocity and ultimately the discharge measurement. To minimize error from this source, the ADV water temperature sensor is compared side-by-side to a separate handheld temperature sensor each day of use (Ecology 2021a). This side-by-side temperature is noted on the discharge measurement form. In addition, in subsequent discharge measurements on the field excursion, the ADV temperature is noted on the field form for future comparison if required. We use field thermistors that are checked against a National Institute of Standards and Technology (NIST) referenced thermometer to perform these water temperature quality checks. The water temperature measured by ADV should be within 2°C of the independent water temperature measurement.

If the ADV's temperature sensor differs consistently from the independent temperature measurement by 2°C or more, or if the instrument temperature sensor has failed, the ADV should not be used to make discharge measurements until the temperature sensor is repaired and checked (Blanchard 2010).

6.2.1.2.2 Bias in ADCP measurements

There are several sources of potential bias in ADCP measurements, including internal magnetic compass errors, electromagnetic interference, Global Positioning System (GPS) multi-path errors, directional biases, moving bed conditions, and water temperature biasing velocity measurements.

Compass errors can cause bias in velocity angle determination, boat direction, and boat heading. These biases can cause errors in discharge determination. To compensate for compass error, field staff conduct a compass calibration procedure prior to every ADCP measurement. The compass calibration incorporates conditions at each measurement location.

Electromagnetic interference (EMI) can cause fluctuations in heading, resulting in errors in measured velocities, particularly at lower velocities. Electromagnetic interference can be caused by the presence of power lines, electrical grid substations, proximity to cell towers, and other forms of electrical interference. The ADCP post-processing software QRev identifies and warns users of the presence of EMI. We try to minimize the effects of EMI by attempting to identify potential sources before measuring discharge with an ADCP, and if potential sources are near the measurement site, we try to move to a more suitable location.

GPS multipath error is a condition in which GPS signals bounce off obstacles (e.g., tree canopy, bridges, steep banks, etc.) and cause error in the determination of the ADCP's position, direction, and speed. If identified during a measurement, moving away from obstacles can resolve the interference. If GPS is used because the use of bottom-tracking is precluded, we try to move to a location where conditions are conducive to bottom-tracking.

Directional bias is a situation where transect measurements tend to favor a result depending on whether the direction of the measurement starts on the right bank and proceeds to the left bank or starts on the left and proceeds to the right. We minimize directional bias by averaging reciprocal pairs of transects.

Moving bed biases are caused by the downstream movement of substrate. This can result in the ADCP interpreting this movement as the boat moving in an upstream direction. ADCPs determine their relative position and speed by bottom tracking. Accurate bottom tracking relies on a stable, non-moving stream bed. A moving bed adds errant boat velocity detection and causes an underestimation of water velocity (Ecology 2024a). A moving bed test is conducted prior to every discharge measurement. ADCP software saves details of the test and applies corrections to mitigate the effects of moving bed conditions.

Similar to ADVs, the speed of sound bias is removed from velocity calculations using data processing software. Water temperature is used in speed of sound calculations. Erroneous

water temperatures can affect the determination of stream velocities. If the water temperature difference is greater than 2°C, the instrument manufacturer should be consulted, and the temperature sensor should be considered for repair or replacement. Measure water temperature each day using a calibrated thermistor for comparison with the ADCP temperature sensor. View the water temperature in the 'Composite Tabular' window to compare the measured and recorded temperatures. (Ecology 2024a).

6.2.1.2.3 Bias in gage-height measurements

Potential for bias exists in gage height measurements. Direct gage height measurements require determination of the water level against the station gage indexes. Because of wave action, surface bounce, pile up of water against staff gages and stadia-rods, high vertical distances, wind, and bounce of water in reading tape-downs and wire-weight gages, determination of gage height to the 0.01 ft. resolution carries some amount of uncertainty. The SOP EAP042 *Measuring Gage Height of Streams* (Ecology 2022c) instructs field staff to observe the center point in the range of water surface fluctuation as the documented gage index reading. In addition, the range of fluctuation on the gage index is also noted. Bias could be introduced to these determinations and the streamflow record at large by differing tendencies of individuals to read a gage index in moving water and ambient conditions. One individual may interpret the range of water movement and its center point differently from another individual. One way to help mitigate biases in gage-height measurements is to alternate between field staff reading gage indexes.

6.2.1.2.4 Bias in continuous stage records

As stated earlier, the uncertainty in the stage record arises from electronic stage height sensor output differences from the actual water surface height at the PGI.

We must assume instrument drift occurs incrementally over time because we only have bracketing gage height observations at the beginning and end of a roughly six-week period. During that period, stage data are logged every 15 minutes, about 4,000 data points. The assumption is that the least amount of drift occurs at the start of the data set or the initial calibration when the logger and PGI match, then progresses over time until reaching the next calibration point, where the amount of drift is presumed greatest (Ecology 2022d).

We correct instrument drift by adjusting the stage record to the PGI observations. Using data management software, these corrections are applied incrementally over the period between site visits. These incremental corrections may bias the stage record because of the assumption that logger drift occurs steadily over time. However, logger drift may not occur steadily. Logger drift may occur at a larger rate because of rapidly fluctuating stage or because of extreme high or low events. Since the stage record is typically corrected for drift incrementally, it is possible that the corrections to the stage record may not result in the data reflecting the true stage at individual data points. However, we are forced to apply this assumption because gage height observations are not collected between site visits.

One method we have at our disposal to determine gage height independent of the logger record is the use of crest stage gages (CSG). CSGs provide a valuable record of peak stages after the occurrence of high streamflows during the water year (Mastin 2017). At stations with a CSG, it is possible to limit potential bias in logged peak stages during high streamflow conditions that may be more prone to instrument drift, depending on site conditions and sensor placement. The CSG allows for documenting the maximum gage height and any additional intermediate peaks that occurred during the water year without being on-site for the event. If the logged peak in the stage record differs from the observed CSG gage height, the record may be adjusted to the gage height at the CSG. The adjustment would apply to the period from the time of the previous gage-height observation to the time of the most recent peak in the stage record. Further, the stage record adjustment from the time of the crest would continue to the next gage height observation.

6.2.1.3 Sensitivity

Sensitivity in the context of streamflow gaging primarily refers to the ability of submersible transducers, bubblers, and radar gages to measure fluctuations in stage. Additionally, sensitivity represents the threshold of flow measurement instrumentation to accurately measure and detect low velocities with minimum uncertainty.

6.2.1.3.1 Sensitivity of Logger Stage Samples

In the case of electronic stage height sensors, we focus on the capability of these instruments to detect minimal changes in water surface elevation. The objective is to record stage data within 0.01 feet of the reading of the PGI, or within 0.2 percent of the effective stage. In this context, the effective stage refers to the height of the water surface above the orifice or sensor. For example, at an effective stage of 25 feet, the required accuracy would be 0.05 feet (0.2 % of 25), and 0.01 feet at five or less effective stage (Mastin 2017). The streamflow monitoring program purchases stage-height sensors following these minimum requirements. In some circumstances, such as at larger rivers where the stage range is large, or instances where stream turbulence precludes a precise stage determination at the gage index, that level of accuracy is unattainable (Mastin 2017).

6.2.1.3.2 Sensitivity of Velocity Measurements

The streamflow monitoring program uses two distinct instruments to measure velocity, ADCPs and ADVs.

Monitoring program staff use an ADV to conduct wading measurements. The low velocity threshold for the instrument is 0.10 feet per second (ft/s) (Mastin 2017). Although the instrument will measure velocities less than 0.10 ft/s, the velocity error at 0.10 ft/s is about four percent. If any measured velocity at over half the verticals in a cross-section is less than 0.10 ft/s or the average velocity for the measurement is under 0.10 ft/s, we do not rate the measurement any better than fair.

Due to the configuration of the ADV sensor head and the potential for interference at shallow depths, there are limitations to the velocity observation spacing interval and the depth at which we can measure an accurate velocity. The minimum spacing of velocity observations between verticals is 0.3 feet. The minimum depth that can produce a reliable value is 0.20 feet.

ADCPs will typically not measure in depths less than about 0.7 feet (except at the margins). The accuracy of velocities less than 0.30 ft/s are considered unreliable. (Ecology 2024a).

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

Standard methods and procedures—as presented in relevant Standard Operating Procedures (SOP) are followed, ensuring comparability of current results to past records.

Staff across the state maintain consistency in methods by operating from the same SOPs and using the same equipment. A comprehensive list of SOPs can be found in Table 8 below.

Table 8. Freshwater Monitoring Unit streamflow standard operating procedures (SOP).

Standard Operating Procedure Title	SOP Number	Author and Date
Standard Operating Procedure for Measuring Gage Height of Streams, Version 1.2	EAP042	Shedd 2022
Operation of the Teledyne RD Instruments RiverPro Acoustic Doppler Current Profiler, Version 2.1	EAP055	P. Anderson 2024
Standard Operating Procedure for Measuring and Calculating Stream Discharge, Version 1.3	EAP056	Shedd 2021
Standard Operating Procedure for Conducting Stream Hydrology Site Visits, Version 1.3	EAP057	Burks 2022
Measuring Stream Discharge using SonTek® Acoustic Doppler Velocimeters, Version 2.0	EAP058	Burks 2021
Standard Operating Procedure for Operation of Mechanical Velocity Indicators, Version 1.4	EAP059	Clishe 2023

Standard Operating Procedure Title	SOP Number	Author and Date
Standard Operating Procedure for Measuring Stream Discharge from a Bridge Using Mechanical Equipment, Version 2.3	EAP060	Shedd 2023
Standard Operating Procedure for Basic Use and Maintenance of WaterLOG® Data Loggers and Peripheral Equipment, Version 2.1	EAP072	Bookter 2023
Standard Operating Procedure for Correction of Continuous Stage Records Subject to Instrument Drift, Version 1.3	EAP082	Shedd and Springer 2022
Standard Operating Procedure for Basic Use of Sutron® SatLink 3 Logger, Version 1.0	EAP089	Bookter 2024

6.2.2.2 Representativeness

The following criteria are intended to guide site selection to be the most representative of streamflow conditions of interest in the watershed. We attempt to locate gaging stations in a reach that best meet the following criteria:

- Channel is relatively straight, with well-defined and parallel edges up and downstream of the cross-section.
- The channel is free of excessive vegetative growth, large cobbles, and boulders.
- Measurement cross sections are available with sufficient depth year-round.
- Discharge is distributed evenly across the channel.
- The gage location is a sufficient distance from tributary inflows and close to channel control structures that influence the stage-discharge relationship.
- Discharge is contained in a single channel at the full range of stage with limited braiding.
- The stage/discharge relation is regulated by a well-defined control.

The location of the gage is sometimes dependent on client needs and our ability to access the site. Sometimes the location of our gages might not be the most representative site on the stream for monitoring purposes. It is often a compromise between collecting good representative data, meeting our client's needs, and our ability to access a monitoring location.

The stations are visited every six weeks, on a schedule designed to capture conditions that represent the distribution of streamflow throughout the water year. This equates to about eight discharge measurements per year. Additional site visits are sometimes made to capture extreme events (high and low) to better define the range of discharge throughout the year.

6.2.2.3 Completeness

Our goal is to publish the mean daily discharge on 95% of the days comprising a water year. Ideally, a complete record of streamflow throughout the water year is collected. This is not always possible due to equipment malfunction or limited site access. This can impact the overall number of station visits in a year and the completeness of the data set. In addition, the completeness of the streamflow records may be due to Freshwater DataStream discharge reporting restrictions or data quality limitations.

In some instances, stage data points are missing or, for various reasons, are of compromised quality. In such cases, attempts are made to replace the erroneous or missing data with well-correlated stage data from nearby stations with similar-sized drainage areas. In addition, annual streamflow data sets may not include values in which the predicted discharge exceeds the range of rating curves.

We aim to publish discharge throughout the stage range encountered at a gaging station. Ideally, the range of discharge measurements corresponds to the range of recorded stage. However, this is not always the case as streamflow extremes, particularly those occurrences that are high, are difficult to time in a way that field staff can measure when they occur.

We do not publish discharges that exceed twice the value of the highest measured discharge defining an active rating curve (Rantz 1982). For example, suppose the highest measured discharge defining a rating curve is 1,000 cubic feet per second (cfs), we extend the reportable range of the rating curve to the stage corresponding to 2,000 cfs. We would not report or publish discharges exceeding the stage corresponding to 2,000 cfs in this example.

Where appropriate, we develop and apply open channel streamflow models to predict streamflows higher than two times the highest measured discharge. The streamflow model application is discussed further in section 8.2.3.

Special consideration is required for discharges less than one-half of the lowest measured discharge defining an active rating curve. If a point-of-zero flow (PZF) has been determined at the gage control corresponding to the active rating curve, then the publishable discharge range can extend to the PZF.

Published streamflows below one-half of the lowest measured discharge should be flagged as estimated in rating curves without a measured PZF. If the current lowest measured discharge was not conducted when streamflows were low, typically in the early development of a new rating curve, when a robust range of discharges has not yet been measured, suspension of reporting these discharges to the Freshwater DataStream should be considered.

Rating curve development applications (e.g., BARC) can be used to estimate the stage-discharge relation in low discharges. Professional judgement and knowledge of channel and streamflow conditions should be considered when choosing to publish estimated discharges below one-half of the lowest measured discharge.

6.3 Acceptance criteria for quality of historical data

EAP's streamflow monitoring efforts began in earnest in the early 2000s. Over the years, the program has made significant improvements in methods, equipment, and technology. Additionally, we have developed in-house utilities and utilized various existing applications to increase our capabilities to assess the quality of discrete discharge measurements and evaluate the uncertainty of streamflow records. Important improvements were made in rating curve development with the use of utilities made available from the USGS. In addition, USGS techniques were researched and utilized to address special streamflow circumstances, including rapid fluctuations in stage during discharge measurements, and channel storage calculations in circumstances when discharge measurements are conducted at significant distances from the gage. Open-channel streamflow modeling procedures were also developed, making it possible to publish discharges beyond the measured range (Benson and Dalrymple 1967).

Streamflow records measured with earlier types of equipment and methods, during the early phases of the program, may not meet current Measurement Quality Objectives (MQOs) but are still considered valid historical records after senior-level review is completed. Streamflow records from recent years are considered superior because of continuous technological advancements and ongoing training of FMU staff.

Throughout its history, the program has made significant technological advancements in methods and equipment, as well as continued training of monitoring program staff. Below is a timeline of how the program made advancements over the years:

- Pre-2002. Stage record and regression-based stage-discharge rating curves were managed in Microsoft Excel software. Discharge measurements were conducted almost exclusively with mechanical velocity observation measurement equipment (propellers). Data review was rudimentary in this period.
- 2002 – 2009. The streamflow monitoring network significantly expanded across the state and acquired the Hydstra data management platform. We began transmitting continuous data in real-time through Geostationary Operational Environmental Satellites (GOES) telemetry, expanded the use of acoustic Doppler instrumentation, and published the first QAMP. We also began aligning our standard operating procedures with those of USGS methods and improved online discharge data publishing with the introduction of technical notes, which summarize the water year at each gage. Data quality improved over this period because of these additions and enhancements. Data review and publishing also became more comprehensive.
- 2009 – present. Developed automated error assessment to augment the senior-level data review process. Acoustic Doppler technology continued to improve. Stage measurement instrumentation technology improved with the acquisition of radar gages. Continued to develop procedures to improve our measurement and data quality analysis procedures. Continued alignment with USGS methods.

6.4 Model quality objectives

Does not apply to streamflow monitoring activities.

7.0 Study Design

7.1 Study boundaries

All work associated with this monitoring program is conducted within Water Resource Inventory Areas (WRIA) identified by the state of Washington. The following list (Table 9) details which WRIs across the state currently have active streamflow monitoring stations and the number within the boundary.

Table 9. Number of active gages in Washington State Water Resource Inventory Areas (WRIA).

WRIA Number	WRIA Name	Number of active gages
1	Nooksack	3
3	Lower Skagit-Samish	3
5	Stillaguamish	5
7	Snohomish	1
17	Quilcene-Snow	5
18	Dungeness-Elwha	8
19	Lyre-Hoko	2
20	Sol Duc-Hoh	1
22	Lower Chehalis	1
23	Upper Chehalis	7
24	Willapa	1
25	Grays-Elochoman	2
26	Cowlitz	1
28	Salmon-Washougal	1
29	Wind-White Salmon	1
32	Walla Walla	10
34	Palouse	1

WRIA Number	WRIA Name	Number of active gages
35	Middle Snake	2
38	Naches	1
39	Upper Yakima	5
45	Wenatchee	4
48	Methow	2
59	Colville	1

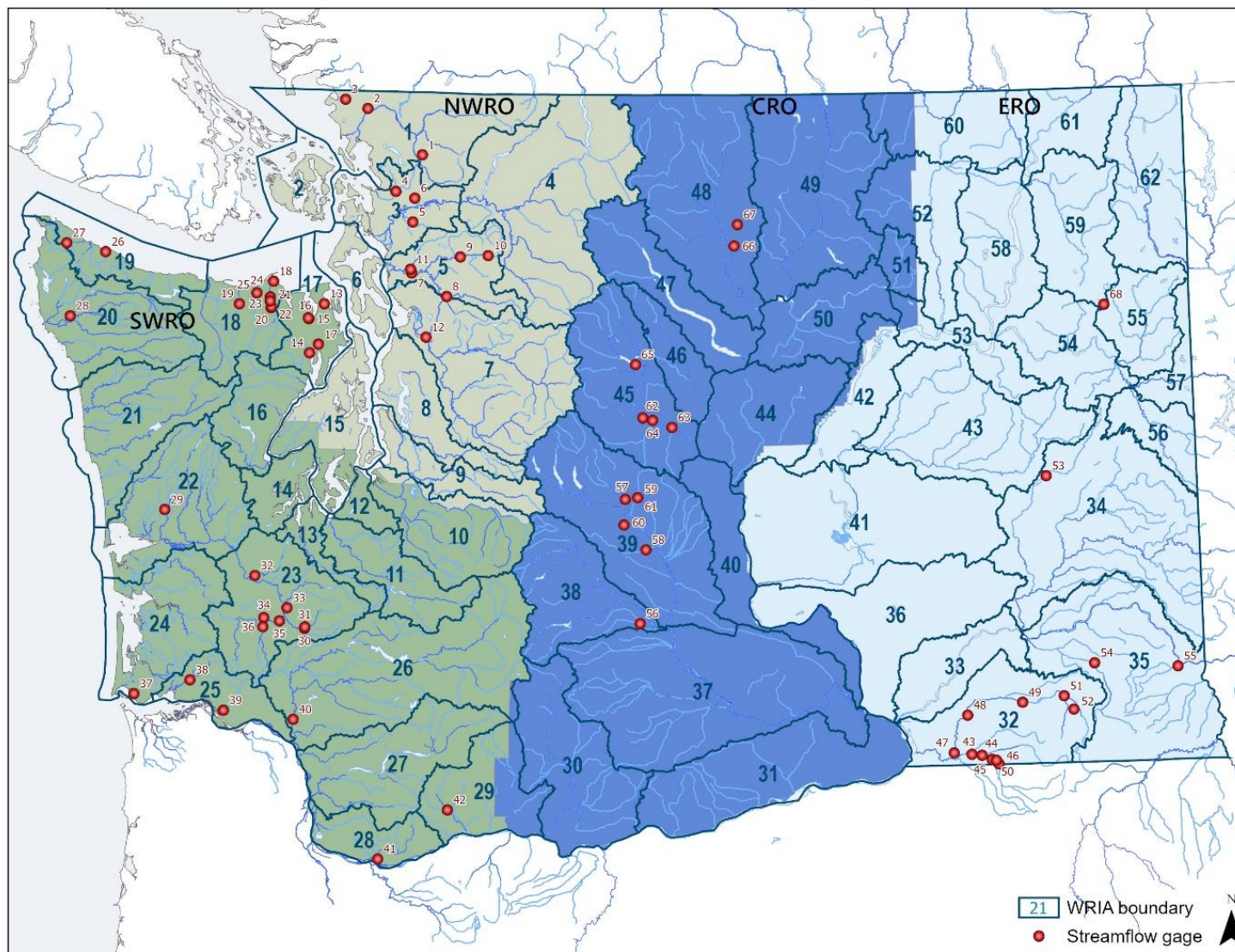


Figure 2. Active streamflow monitoring stations with the distribution of stations across state WRIA's.

7.2 Field data collection

7.2.1 Sampling frequency

Basin leads visit monitoring program, gages at scheduled dates approximately every six weeks. Circumstances such as infrastructure and equipment problems, high and low streamflow events, or the needs of the client may require additional site visits. Typically, this results in seven to ten site visits per year.

This frequency of site visits allows for effective operation and maintenance of the gage. Keeping the station powered and in good working order requires regular site visits. These visits allow the basin lead to confirm station infrastructure has not incurred damage, and that parameters transmitted to the Freshwater DataStream are reliable.

Each site visit includes observation of the gage height of the monitored stream. Basin leads cross-check all accessible gage indexes against each other and the logged stage record at the gage (Ecology 2022c). In addition, streamflow measurements are conducted at these visits. Regular discharge measurements and rating curve maintenance ensure reliable streamflow data are transmitted to the Freshwater DataStream. Additional discharge measurements conducted outside of the six-week scheduled visits, typically during high or low streamflow periods, are critical to improve the accuracy and publishable range of discharge at a gaging station.

7.2.2 Field parameters to be measured

Stage and discharge are the two principal field parameters we measure. In addition, most gages log the secondary parameters of air and water temperature to help assess on-site conditions, such as periods of ice-impacted stage records.

Stage is measured in feet and verified through the use of multiple types of indexes or structures at the gage site, including laser levels, staff gages, wire-weight gages, tape-down reference points, and crest-stage gages. Refer to SOP EAP042: *Measuring Gage Height of Streams* document (Ecology 2022c) for descriptions of gage index types. Not all stage indexes are present at each gage. Individual gages will have two or three indexes from which stage is measured. Each gage must have a minimum of two points from which gage heights are measured, and cross-checked.

Discharge, published in cubic feet per second (ft^3/s), is determined by direct measurements of the width of a stream at a cross-section, depths through the cross-section, and velocity. From these direct measurements, other sub-parameters associated with discharge, such as area, wetted perimeter, among others, can be determined. Refer to SOP EAP056: *Measuring and Calculating Stream Discharge* (Ecology 2021b) for further definitions of discharge parameters.

7.3 Modeling and analysis design

Not applicable in this context.

7.4 Assumptions underlying design

Many assumptions underlie a streamflow monitoring program. The primary assumptions include the following:

- The selected site of a streamflow monitoring station is representative of the cumulative natural and human influences on water quantity in the watershed above that location.
- Conducting site visits on a six-week interval is a sufficient frequency to maintain a discharge rating curve representative of streamflow conditions across a water year.
- Continuous monitoring of stage at 15-minute intervals is representative of stage fluctuations on each day.
- While measuring gage height, the center point in the range of water surface fluctuation observed at a gage index correctly represents stage.
- Discharge measurements capture all water flowing through a channel. Hyporheic flow, or water flowing through the substrate, remains unmeasured. Hyporheic flow is more pronounced and a larger portion of total discharge in low streamflow conditions (Mastin 2017).
- In all discharge measurements, whether a point velocity or a Doppler profiled velocity, the actual measured portion of the cross-section is correctly extrapolated to the unmeasured portion.
- Point velocity samples made in a discharge measurement cell reflect the true velocity of the measured section.
- The velocity profile in the discharge measurement vertical is logarithmic, i.e., velocities are slower towards the bottom of the vertical and faster near the top.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Occasionally, circumstances may preclude scheduled site visits, including but not limited to:

- Unsafe driving or working conditions due to inclement weather may force site visits to be postponed or canceled.
- Road construction closures can prevent access to a site.
- Equipment malfunctions.
- Unsafe streamflow conditions that would result in injury or damage to equipment.
- Dewatered channel conditions in the gage reach.
- At some stations, scheduling site visits is dependent on tidal conditions.

- Public recreational activities (fishing, swimming, etc.) at the discharge measurement location.

Typically, good planning and awareness can help avoid or mitigate the most problematic circumstances that arise.

7.5.2 Practical constraints

Practical constraints that might limit data collection include:

- Limited staff availability.
- Limited vehicle access due to maintenance or availability.
- Damaged station infrastructure due to high streamflow events or vandalism.
- Delays or limited availability of needed equipment, materials, and supplies.

7.5.3 Schedule limitations

Limitations that affect the project schedule include staff availability, inclement weather, equipment and vehicle availability, extreme streamflow conditions, and site accessibility. Usually, rescheduling or cancelling a field trip because of challenges such as those described in 7.5.1 and 7.5.2 creates manageable impacts to operations. However, impacts on data quality may follow if the contingencies and challenges described above are not addressed effectively.

8.0 Data Collection and Processing Procedures

8.1 Invasive species evaluation

Encounters with invasive aquatic plant and animal species are likely to occur while wading in the rivers and streams of Washington state. We will strictly adhere to the measures outlined in Ecology's SOP EAP070: *Minimizing the Spread of Invasive Species* (Ecology 2024c). Details of procedures are outlined in the Standard Operating Procedure (SOP), but in brief, we will: (1) inspect and clean our waders, and all equipment when leaving a gaging station and/or before visiting another waterbody, and (2) apply further decontamination procedures when the risk of spread of aquatic invasive species is highest and/or we are visiting gaging stations in watersheds identified as of "extreme concern" (Ecology 2024c).

8.2 Site operations, discharge measurement, and post-processing procedures

In order to meet the general objective of providing a comprehensive assessment of streamflow conditions in Washington State, the streamflow monitoring program's major task is to predict discharge throughout the entire range of stage over time. To complete this task, we must accurately monitor stage and produce reliable rating curves. Additional tasks include conducting accurate discharge measurements and developing reliable high streamflow models when necessary. We must also identify and correct for the movement of gage structures relative to the station through differential levels.

We implement and document procedures designed to successfully perform these tasks. In addition, methods are developed to address the quality of equipment performance, discharge measurements, discharge rating curves, field procedures, and continuous data records.

8.2.1 Site operations and maintenance

8.2.1.1 Time

Monitoring program data loggers are set to Pacific Standard Time (PST), and field staff observe PST the entire year. Field notes should include the time zone designation "PST" appended to all times to reduce ambiguity. All entries to the databases are entered in PST as well. All time stamps in field data and notes collected during the Pacific Daylight Time season should be verified and adjusted if incorrect.

8.2.1.2 Site visits

An important aspect of stream gage site visits includes infrastructure, site, and equipment inspection and maintenance (Ecology 2022b). Basin leads ensure the site is accessible and in a safe condition. We carefully inspect gage structures and equipment, making certain they are in good repair and operating properly. The basin lead ensures:

- The battery voltage is checked at every visit.

- The condition of desiccant chambers or packs is checked.
- The condition of solar panels, Geostationary Operational Environmental Satellites (GOES) radio antennas, Global Positioning Systems (GPS) receivers, and other components is inspected for damage or fouling and cleaned if necessary, and when safe to do so.
- Wiring connections and conduit containing sensor wires are inspected.
- Debris collected on instream structures such as staff gages and terminal ends of pipe runs is cleared if safe to do so.
- Reference points and marks are intact and accessible.
- Grass, brush, tree limbs, etc., around the site are kept trimmed or removed for access, safety, and proper operation of the station.

Minor maintenance and repairs can be carried out on site by the basin lead. Field vehicles carry basic tools and some spare parts and components. Significant repairs, station upgrades, and installations beyond the scope of the basin lead are carried out by the engineering technician.

After site inspection, the visit continues with the observation of gage height (Ecology 2022c). Next, stream discharge measurements are conducted during the visit, as well as a determination of the point of zero flow when possible (Ecology 2021b). Finally, during most site visits, the latest data set is downloaded from the data logger to a data media device (Ecology 2022a).

8.2.1.3 Gage datum

The stage or water surface elevations at stream gaging sites and the elevations of all reference marks, reference points, and gage indexes are relative to a common datum. At most stations, we arbitrarily assign a datum corresponding to the elevation of the primary gage index (PGI). PGIs are installed such that the assumed zero point is below the point of zero flow and expected scour of the channel. This practice ensures gage heights will not be observed at less than zero feet. However, at the time of this writing, we are beginning to embark on establishing gage elevations based on the standardized North American Vertical Datum of 1988 (NAVD 88).

8.2.1.4 Differential levels at gaging stations

Our streamflow monitoring station's gage height recorders, all reference marks and reference points, as well as PGI and secondary gage indexes (SGI), are referenced to a station-specific or geodetic gage datum. The purpose here is to ensure the supporting structures of gages, such as laser pads, staff gages, bridges supporting wire weight gages, and tape-down reference points, have not moved over time. This movement is often due to settling or uplifting from earth movement, ice-heaving, or damage from high streamflow events. Vertical movement of these structures results in errant readings of gage heights. Differential leveling, a process using surveying equipment to determine the difference in elevation between two or more points, is

used to establish the gage datum and perform periodic checks for vertical movement of these structures. The streamflow monitoring program staff follow the differential leveling techniques and error thresholds adopted by the United States Geological Survey (USGS). Kenney (2010) describes the field procedures, calculation methods, and thresholds related to allowable error-of-closure, collimation thresholds, and other details.

Upon installation of a streamflow monitoring station, levels are conducted to establish the datum, elevations of gage indexes, related reference marks, and points relative to the datum. Levels are run at a minimum of every three years thereafter. Levels should be run as soon as possible when there are unresolved discrepancies between gage observations or movement of gage structures, reference marks, or reference points. The threshold for the confirmed vertical movement of the PGI, triggering correction to streamflow records, is 0.015 feet (Mastin 2017).

We observe and document stage to the 0.01 foot. Levels resolution must be greater and is set at 0.001 feet (Mastin 2017). Differential levels require a minimum of two foresights from two independent instrument elevations to all PGI and SGIs, reference marks, and reference points.

8.2.1.4.1 Collimation error

Prior to each levels trip, collimation error is assessed. We determine the collimation error through a two-peg test (Kenney 2010). Collimation refers to the inclination of a level's line of sight (i.e., the line of sight may not be level even though the instrument is level upon setup) and is expressed as $n \text{ feet}/100 \text{ feet}$, where n equals the determined collimation error. Collimation errors are systematic, meaning the error is preserved in all foresight and backsights (Kenney 2010). Collimation error, if uncorrected, adversely affects final elevation determinations. Maximum allowable collimation error in a two-peg test should not exceed $|0.003| \text{ feet}/100 \text{ feet}$.

8.2.1.4.2 Circuit-closure error

Circuit-closure error refers to the difference between the given elevation of the origin reference mark of the levels circuit and the final elevation of that same reference mark as determined by the levels circuit. Closure error is calculated as:

$$CE = G_{el} - F_{el}$$

Where:

CE = Closure Error

G_{el} = Given Elevation

F_{el} = Final Elevation

The allowable vertical closure error for gaging circuit-levels is determined by multiplying the uncertainty constant used for gage station levels of 0.003 feet, times the square root of the number of instrument setups in the levels circuit, including initial instrument setups in the form:

$$CE_{limit} = 0.003 (\sqrt{n})$$

Where:

CE_{limit} = the allowable closure error,

n = the number of instrument setups

In addition, the absolute vertical difference between the first and second elevations for each point must be less than 0.005 feet. Differences greater than 0.005 feet require an additional two separate foresight measurements from independent instrument elevations to the point(s) in question. A new closure error for the abbreviated circuit must be calculated, and the results must fall within the allowable closure error.

All elevations, including closure error and allowable closure error, are calculated immediately after completion of the levels circuit. If the allowable closure error is not met, the levels circuit must be repeated.

We use a purpose-built Excel spreadsheet available on the appropriate EAP server to calculate differential levels results. The calculation form determines closure error, acceptable closure error, and distributes error to all circuit elevations. After review by senior staff, the calculation spreadsheets are archived electronically with station records.

8.2.1.5 Measuring gage height

We deploy several types of gage indexes to measure gage height. These include staff, wire weight, laser level, tape-down, and crest stage gages. At each station, one of these types of gages, except for tape-down and crest stage gages, is designated as the PGI. The PGI is the base gage, directly referenced to the continuous logging gage, and at most stations, the basis for the station datum.

A vertical standing staff gage consists of a singular or a successive series of enameled steel plates mounted to a secure structure. Most staff plates used are graduated in 0.02-foot increments. Staff gage observations are recorded to 0.01 feet resolution.

Wire weight gages are gage-height-measuring instruments of a known elevation, typically attached to a bridge railing or parapet over a stream. From the gage, a weight is slowly lowered to the water surface. A counter on the gage displays the gage height determined by the vertical distance to the water surface. The gage is housed in a locked protective covering.

Laser level pads, a gage index developed and implemented by the Freshwater Monitoring Unit's (FMU) streamflow monitoring program, utilize industrial-grade laser levels and stadia rods to determine gage height. The laser level, a portable device mounted on a permanently installed structure or pad of known elevation, emits a laser beam on a level plane. Reference marks are placed in the vicinity of the laser level pad. Elevations of the reference marks relative to the pad are predetermined through initial levels operations. At routine site visits, elevation differences between the laser pad and reference marks are measured using the laser level and stadia rod. These measurements are compared with the predetermined elevation differences to confirm

that the laser level pad position has remained static. Vertical differences greater than 0.02 feet between the laser pad and the predetermined reference mark elevations should be investigated by the basin lead, and levels run if necessary. For more information regarding the usage and operation of a laser level gage index, refer to SOP EAP042: *Measuring Gage Height of Streams* (Ecology 2022c).

Measuring gage height by tape-down involves lowering a weighted measuring tape to the water surface from a reference point of a known elevation. The reference point usually consists of a stainless-steel washer secured to a bridge railing. The accuracy and precision of tape-downs in determining stage height are generally inferior to those of the other methods described in this document. This is due to the distance between the observer and the water surface, and most notably, the potential influence of wind on the fiberglass tape used for observation. The program uses tape-downs for an SGI only.

All stations include an SGI in addition to the PGI. PGIs and SGIs are placed collectively in the gage pool, subject to the same station control, and as close in proximity as possible to the stage sensor. SGIs are used to confirm the PGI height and estimate gage height if the PGI is unusable.

The stage measurement equipment and methods previously described are designed to determine stage instantaneously. Alternatively, crest-stage gages provide a valuable record of peak stages after the occurrence of high streamflow. The gage is reliable and relatively simple to install and operate (Rantz et al. 1982). Crest-stage gages consist of a galvanized pipe capped on both ends with a wooden dowel contained in the pipe. The wooden dowel rests on a bolt extending through the bottom of the pipe, which serves as a reference point of known elevation. The bottom cap contains granulated cork. As water rises in the pipe, the cork floats on the water. When the water reaches its peak and begins to recede, the cork sticks to the wooden dowel, marking the crest of the high-water event. Crest stage gages (CSGs) provide an independent verification of peak stage after high streamflow events. Debris lines, or high-water marks left behind by peak streamflow events, can also be used to estimate gage height. Ecology (2022c) describes in more detail the features and uses of gage indexes that we deploy.

We use three types of stage sensors connected to continuous data loggers. These include automated non-submersible pressure transducers (or “bubblers”), submersible pressure transducers, and radar gages. Automated bubblers are devices that emit gas bubbles at a measurable pressure corresponding to stream stage. Submersible pressure transducers anchored at a fixed in-stream location measure water pressure that corresponds to stream stage. Radar gages mounted on bridges or other structures above a stream measure the vertical distance between the gage and the water surface to determine stage.

8.2.2 Discharge measurement and processing

8.2.2.1 Measuring discharge

Monitoring program staff measure stream discharge at every or nearly every gage site visit. The objective is to measure as wide a range of discharges as possible to construct a rating curve that accurately predicts discharge across the entire range of stage.

We currently use four basic methods to measure stream discharge. The most common method is done by wading an instream cross section with a standard 4-foot top-set wading rod, and an Acoustic Doppler Velocimeter (ADV) (Ecology 2021a) or, in very rare cases, a conventional mechanical current meter (Ecology 2023a). A second method is measuring discharge from the deck of a bridge, using either a conventional mechanical current meter (Ecology 2023b) or an Acoustic Doppler Current Profiler (ADCP) (Ecology 2024a). A third method is measuring discharge from a boat, again using either conventional mechanical current meters or an ADCP. The fourth method involves the use of an ADCP, towed bank to bank using ropes. Each of these methods requires specific, specialized equipment and procedures. The method selected depends on the width, depth, velocity, and other physical conditions in the cross-section (Ecology 2021b).

The cross-section should be relatively close to the gage control to avoid inflows from tributaries. This proximity also limits differences in relative discharge between the control and cross-section during periods of changing stage. In low streamflow conditions, emphasis is placed on measuring as close to the control as possible. Hyporheic flow (the portion of the streamflow flowing through gravel substrate) is variable across short distances. The gains and losses between hydraulic connections between groundwater aquifers and the stream channel are typically more pronounced during low streamflow conditions (Mastin 2017).

During extreme streamflow conditions, discharge measurements may be conducted with mechanical instruments or electromagnetic velocimeters. High streamflow conditions may be too deep and swift to measure with an ADV. These conditions may also preclude the use of an ADCP. The ADCP may not collect accurate data during extreme high streamflow because of turbulence and aerated water. Extreme high streamflow can also capsize the ADCP raft, risking loss or damage of the ADCP.

Conversely, low streamflow conditions can be too shallow, slow, and clear to measure with an ADCP. Ultra-clear water (low turbidity) can have too few suspended particles for ADCPs and ADVs. Acoustic Doppler instruments measure water velocity by bouncing acoustic waves off suspended particles. In addition, channels with large boulders, logs, or other structures known as boundaries can cause interference with ADV acoustic signals (Ecology 2021a).

In most cases, relocating to a more favorable cross-section improves measurement capabilities. However, there are instances when mechanical or electromagnetic-based instruments are required. These instruments are calibrated following the manufacturer's specifications. SOP EAP059: *Operation of Mechanical Velocity Indicators* (Ecology 2023a) explains in detail the methods used to calibrate, test, and maintain mechanical indicators.

8.2.2.2 Basic discharge measurement procedures

8.2.2.2.1 Cross-section selection

A key step of the discharge measurement procedure is to select a cross-section with features that will produce the best quality measurement in the gage reach. Field staff look for the following features in an ideal measurement cross-section (Ecology 2021b):

- A stream channel that is relatively straight with parallel edges upstream and downstream of the cross section.
- Defined edges on both sides of the cross-section, with streamflow confined to a single channel.
- A channel of uniform shape.
- A channel free of vegetative growth, large cobbles, and boulders.
- A cross-section free of eddies, slack water, and turbulence.
- A cross-section with depths greater than 0.5 feet.
- Velocities greater than 0.5 feet per second and distributed evenly through the cross section.

Meeting all the selection criteria is often not possible. Field staff should choose the best available cross-section based on the above guidelines.

Cross-section selection and preparation, as well as all instrument tests and pre-deployment procedures, are executed prior to making gage index observations. Gage indexes are observed immediately before and after the measurement. The purpose is to limit the time available for stage to change prior to and after the measurement.

8.2.2.2.2 Method selection

After the cross-section is chosen, field staff select the appropriate instrument to conduct the discharge measurement, given the current streamflow conditions. The cross-section is prepared based on the instrument choice and method of deployment. Stream edges are delineated, establishing the start and end points of the measurement. In the case of wading deployments with an ADV, a measuring tape or tagline is extended from the right side of the channel to the left, perpendicular to the direction of flow. The right and left edges of a channel are oriented looking downstream.

When a stream is measured using the wading method, the cross section is divided into about 30 cells such that approximately five percent and no more than ten percent of the total flow comprises any one cell. Verticals—points in the cross-section at the center of the measurement cell, where depth and velocity are measured—are positioned closer together where flow is more concentrated, and velocity variation or bottom irregularities are greatest.

The wading measurement commences at the right bank and proceeds to the left. Depth and velocity are measured at each vertical. Depths measured with a wading rod are observed to the 0.01-foot resolution. Velocities are measured for 40 seconds. The distance of the vertical from the start point on the right bank, measured depths, and velocities at the vertical are noted. In

addition, channel and streamflow conditions and other notable circumstances are documented. At the conclusion of the measurement, field staff apply a quality assignment (discussed later in this section) to the measurement based on observed conditions of the stream channel, the measurement cross-section, the control, and the summary output and quality information provided by the instrument software.

Cross-section selection is also very important in ADCP deployments. Just like wading deployments with an ADV, straight channels with uniform shape and other physical criteria previously described make for superior, more reliable measurements. After selecting the cross-section, we choose between two primary methods of ADCP deployment, both of which use a small, unmanned boat with ADCP mounted to the hull. Our preferred methods are either towing it from shore to shore or towing the ADCP boat from a bridge. In either method, good control of the ADCP boat is maintained through high velocities, shear zones, and areas of turbulence with two tow lines, each handled by a separate person.

In cases where the preferred methods are not applicable, we consider alternatives. Occasionally, ADCPs are deployed from a manned boat in applications on large streams where wading or towing methods are not possible. ADCP deployment method by wading is the least preferred and should only be used on wadable streams where towing from shore to shore or a bridge is not available or practical (Ecology 2024a).

8.2.2.2.3 Calculating discharge

The FMU's Streamflow Monitoring Program uses the United States Geological Survey (USGS) midsection method to calculate discharge measured with mechanical current meters or ADVs. The midsection calculation method involves summing the discharges of the individual cells comprising the cross-section. The discharge of an individual cell is the product of its area and mean velocity normal to the cross-section. For a comprehensive explanation of the method, refer to SOP EAP056: *Measuring and Calculating Stream Discharge* (Ecology 2021b). The equations comprising the midsection method are written into a variety of available computer programs. The ADV software contains a built-in midsection calculation program to calculate discharge (Ecology 2021a).

The ADCP discharge calculation algorithm differs from the point-velocity midsection method described above, but generally follows the same principle and has a greater density of velocity observations. ADCP discharge measurements are comprised of directly measured and extrapolated components due to the inability of the sensor to measure the entire water column at the top, bottom, and both edges of the channel cross-section. The final discharge is the summation of measured and extrapolated components. The measured portion of the cross-section is similarly divided into cells, called ensembles, through a combination of ADCP auto-configuration and the speed of the boat as it traverses the cross-section. The ADCP sensors can determine the area and velocity within each ensemble, the product of which is discharge, and then all ensemble discharges are summed. For a more in-depth explanation of this concept, refer to Mueller et al. (2013). The discharge calculation algorithm is integrated into the WinRiverII data collection and QRev post-processing software programs.

8.2.2.2.4 Discharge measurement quality assignment

The basin lead assigns the quality of a measurement using a combination of the statistics generated by the discharge measurement instrumentation and professional judgement. This quality assignment requires knowledge and experience of hydrologic principles. The measurement quality assignment is an assessment of the uncertainty between the measured discharge and actual discharge and is partly subjective. ADVs and ADCPs provide a statistical analysis of measurement quality (Ecology 2021a; Ecology 2024a). These software outputs further assist the basin lead in assigning the quality of the discharge measurement. More subjectively, the basin lead also evaluates the characteristics of the channel segment in which the cross-section is located. Post-processing of ADCP measurements is conducted with the USGS application QRev. The QRev utility provides additional and more comprehensive data analysis to assist in measurement quality assignments (Ecology 2024a). The ADV software summary output also provides additional informative statistics.

We express measurement quality assignments as excellent ($\pm 3\%$), good ($\pm 5\%$), Fair, ($\pm 8\%$), and poor (greater than 8%). The percentages associated with the quality assignments reflect the maximum variance between the measured discharge and actual discharge.

8.2.3 Rating curves and high streamflow models

8.2.3.1 Rating curve development

Rating curves are developed over time based on field discharge measurements coupled with gage height observations. Properly developed rating curves establish the stage and discharge relation at a streamflow gaging station.

After a reliable rating curve has been established covering a sufficient range of stage, the rating curve must be regularly updated and verified with additional discharge measurements. The physical structure of a stream's channel changes over time. Depending on hydraulic conditions in the stream, the channel can change significantly by deposition or erosion of bed materials. These changes in channel geometry and structure often alter the stage discharge relation expressed through the rating curve, resulting in incorrect discharge reporting to the Freshwater DataStream. As a result, at most gages we measure discharge about eight times throughout the water year to track changes in channel conditions, adjusting rating curves as needed to maintain accuracy.

The frequency at which rating curves require adjustment depends on the stability of the channel geometry and gage reach control at the monitoring station. If high streamflow events frequently cause scour or fill of a channel, the controls are unstable. If a control changes frequently, the stage and discharge relation may change frequently (Ecology 2021b).

Because most monitoring program streamflow gages transmit data in real-time, rating curves are adjusted as soon as practical when a discharge measurement exceeds both the user-defined ten-percent error boundaries built into the rating curve development application and the amount of variability identified in the quality evaluation of the measurement.

Rating curves are broken up into ranges depending on their level of reliability. We describe the measured range of the rating curve as the portion directly defined by the measurements comprising the rating curve from the lowest measured discharge to the highest. The measured range is the most reliable and well-defined portion of the rating curve. We include in this range an additional ten percent surrounding the highest and lowest measured discharge. The publishable range of the rating curve includes extrapolations of two times the value of the highest measured discharge and one-half the value of the lowest measured discharge. As discussed in section 6.2.2.3, there are methods to extrapolate streamflow less than one-half the lowest measured discharge.

8.2.3.2 High streamflow models

To publish streamflow greater than two times the highest measured discharge, we develop open channel streamflow models using the slope-conveyance or slope-area method. The method uses the cross-section area, wetted perimeter, channel slope, and Manning's bottom roughness coefficients to derive average velocity for a given open channel discharge (Benson and Dalrymple 1967). This technique for expanding the publishable range of discharge at a gage does not apply to all streamflow conditions exceeding the measured range. The ability to produce a model at a location can be limited by the channel and streamflow conditions, the ability to conduct channel control measurements, and other limitations.

Velocity is calculated using Manning's equation:

$$V = \frac{1.49}{n} \left(\frac{A}{P} \right)^{2/3} S^{1/2}$$

Where:

V = average velocity in ft/s

n = Manning's roughness coefficient

A = cross-sectional area in ft²

P = wetted perimeter in feet

S = energy slope in ft/ft

Discharge can then be calculated by the following equation:

$$Q = V \times A$$

Where:

Q = discharge in cfs

V = average velocity in ft/s

A = cross-sectional area in ft²

Cross-sectional areas for unmeasured open channel streamflow are determined by surveyed elevations of the channel and banks, as well as channel slope.

The basin lead assesses and applies a numerical quality code to modeled streamflow predictions based on the average percent difference between measured discharges and scaled modeled streamflow. The scaled streamflow quality code is downgraded when the calibrated results exceed 20% of the measured discharge.

8.2.4 Addressing missing or erroneous data

In some instances, stage data are missing or determined to be of erroneous quality. Missing stage data are replaced with well-correlated, regressed stage data from a reference streamflow gage where possible. Reference gages are located near the gage of interest, in the same climatic environment, and have a similar-sized drainage area. The basin lead ensures a good statistical relationship between the stage data sets. Their regression analysis should focus on a timeframe of sufficient length where similar streamflow conditions as the missing or erroneous period occurred, when both stations were operating. Also confirmed through this process are the timing and magnitude of discharge events such that the data reflect synchronization of hydrographs.

In the case of erroneous or anomalous streamflow records, an evaluation is conducted to confirm their origin or cause. This can help determine how the erroneous period in question is managed. Often, erroneous stage data periods are brief and intermittent because of battery issues, problems with the stage sensor, or the logger, etc. Short-duration periods of erroneous data may only require linear interpolation between endpoints for an adequate resolution. For another example, if a data set fluctuates erratically for a period because of damage to infrastructure or other in-stream conditions, the basin lead may choose to remove the period of suspect data and replace it with data from another station. All data that is removed from the streamflow record archive and subsequently replaced is not deleted and remains available in its original form in the station raw file. In other instances, when data cannot be replaced with data from another gage, such as when periods of icing occur in the channel, the period of erroneous data is given a quality assignment precluding publication of discharge.

8.3 Containers, preservation methods, holding times

Not applicable. Sample containers, preservation methods, and holding times do not apply to streamflow monitoring activities.

8.4 Equipment decontamination

Equipment decontamination procedures do not apply to streamflow monitoring activities.

8.5 Sample ID

Sample identification protocols do not apply to streamflow monitoring activities.

8.6 Chain of custody

Chain of custody protocols do not apply to streamflow monitoring activities.

8.7 Field log requirements

Basin leads take detailed field notes prior to, during, and after each discharge measurement and site visit. Evaluations of measurements and streamflow records depend on complete and thorough notes. Basin leads document all observations, adjustments, required actions, and notable conditions while present at the gage. In most circumstances, the basin lead is the responsible member of the field party to complete all field notes (Ecology 2021b).

At a typical gage site visit, staff record notes to three or four basic note forms. Field notes are written on Rite in the RainTM paper for outdoor durability and stored in a suitable field notebook.

EAP-FMU Stream Gage Logger Notes (form number ECY 070-183) serves as the primary note form to which we document station name and number, field party, logger and instrument information, gage height observations, water and air temperature observations, battery voltages, and more. Ecology 2022b) discusses in more detail the information documented in Stream Gage Logger notes.

Depending on the discharge measurement instrument used, the basin lead uses either ADCP Measurement Notes (form number ECY 070-298) for ADCP measurements or Discharge Measurement Notes for point-velocity, ADV, or mechanical current meter measurements (form number ECY 040-56). Designed to note measurement parameter values and measurement conditions, field staff should populate discharge note sheets completely. Field staff provide as much detail as possible describing the cross-section, streamflow conditions, and hydraulic control. Thorough descriptions inform the final quality rating of the measurement by the basin lead. Field staff will never receive criticism for too much detail describing measurement conditions. Ecology (2021b) discusses more specifically the kinds of information the basin lead include, and protocols followed with respect to discharge measurement notes.

Before departing the gage site, field staff populate the Gaging Station Log (form number ECY 070-330). Staff transcribe to this note form information previously written in the Gage Logger note sheet and notes from the discharge measurement. This form remains in the station house (Ecology 2022b). Populating and keeping these notes at the gage can prove useful for reference purposes at future site visits.

Field notes are considered original legal documents (Mastin 2017). Make necessary corrections to errant observations by crossing out mistaken entries with a single strike-through. Write in the correct observation, including the initials of the person making the change and the date of the change. Do not erase originally written data. For all non-observed parameters for which space is provided in the note sheet, write a strike-through line through the space on the note sheet indicating a non-observation, i.e., when a tape-down does not exist at a gage site. This practice eliminates ambiguity as to whether an observation or measurement was mistakenly

overlooked. When field notes are completed, the observer initials the note form in the upper right-hand corner. Staff transcribe discharge and station site visit notes electronically to the appropriate sockets in the data management platform.

8.8 Other activities

The Stream Hydrology-Technical Coordination Team (SH-TCT), of which all statewide FMU streamflow monitoring program staff, as well as the FMU supervisor, and EAP management members are involved, serves to maintain and improve the quality and timeliness of streamflow records. Additional goals of the TCT include retaining statewide procedural continuity, improving methods, discussing field instrumentation upgrades and maintenance, and maintaining quality standards.

The SH-TCT meets quarterly at a minimum, and more frequently depending on the nature of the issues at hand. The TCT meetings are considered an open forum to bring forth and discuss technical issues related to the measurement of discharge and the operation of continuous streamflow monitoring stations. The SH-TCT staff provides training and guidance in the operation and maintenance of field equipment and instrumentation, as well as both field and office-based standard procedures. Trainings are also made available to TCT staff that may include safely working in flowing water, chainsaw operation and maintenance, and wilderness first aid courses, among other topics.

Additionally, when the need is identified, staff are sent to outside classroom and field trainings for new or more complex procedures, station instrumentation, and data management software as required. Typically, a small cohort is sent to the off-site training, and they return with the knowledge base that benefits the entire TCT.

Annually, the SH-TCT holds a “Methods Day,” a day devoted to training in one or two related activities. In most cases, and especially if a new concept or type of field instrumentation is introduced, the day of training will include a combination of both field and office data management tasks. The topic of the methods day is decided upon collectively by the TCT well in advance of the event.

9.0 Laboratory Procedures

9.1 Lab procedures table

Laboratory procedures do not apply to streamflow monitoring activities.

9.2 Sample preparation method(s)

Laboratory procedures do not apply to streamflow monitoring activities.

9.3 Special method requirements

Laboratory procedures do not apply to streamflow monitoring activities.

9.4 Laboratories accredited for methods

Laboratory procedures do not apply to streamflow monitoring activities.

10.0 Quality Control Procedures

10.1 Continuous stage record

Many quality problems associated with continuous stage records can be avoided with proper site selection and installation of stage sensors before the logging of stage data commences.

The choices of stage sensor and location in or above the stream channel (in the case of radar gages) are very important to the quality of the future continuous stage record. Poorly located stage sensors, as well as primary and secondary gage indexes (PGI and SGI), can ultimately result in an unreliable stage and discharge record. Channel and hydraulic conditions impacting the sensor and gage index locations in the channel should be carefully considered before beginning logging of continuous stage. If the best location for a gage is less than ideal, the basin lead considers the use of a bubble chamber, a device affixed to the end of the conduit housing the stage sensor. A bubble chamber minimizes the impact of wave action and turbulence on the sensor and reduces uncertainty in the continuous stage record. Additionally, the sampling interval of the stage sensor can be adjusted to compensate for the uncertainty associated with challenging site conditions.

Conditions at stage sensor and gage index locations are checked at each site visit. If necessary, actions should be taken, including removing debris from instream stage sensor structures, and resealing sensors if damaged and safe to do so. If data collection issues remain unresolved, relocation of the gage to mitigate adverse impacts to stage and streamflow record quality may be necessary.

Basin leads are responsible for monitoring on-site conditions and assessing the stage record to identify potential problems that result in diminished streamflow record quality. The basin lead reviews the stage hydrograph for any anomalous data points, irregular patterns (i.e., due to ice impact, etc.), or unexplained changes in stage. Once an irregularity is identified and a cause is investigated and documented, corrections to the stage record are applied.

As described in section 6.1, the stage record is confirmed by measurement or observation of the gage indexes. Multiple indexes installed at monitoring gages provide redundancy and a quality check of the stage record in the field.

10.2 Stage field equipment calibration testing

Prior to every field trip, the equipment used in the field to measure gage height is tested for accuracy. Laser levels are checked for proper calibration. Stadia rods and tape-down measurement tapes are tested for accuracy and precision. Equipment used in the field to determine gage height is tested at the facility where stream gaging equipment is stored. Permanent reference points are established such that equipment is tested using the same procedure at the same locations. Permanent reference points help ensure unexpected results do not occur because of problems or inconsistencies in the testing course (Ecology 2022c). Results are saved electronically and stored on Ecology servers.

10.3 Discharge measurement

Most issues adversely affecting the quality of discharge measurements are identified and addressed in the field. Measurement cross-section selection is the most important aspect that determines measurement quality. Choice of instrument used to execute the measurement is also an important consideration (Ecology 2021b).

As described in section 6.2.1.1, the periodic collection of duplicate discharge measurements is used to verify the precision and repeatability of our measurement standard operating procedures.

To ensure measurement quality, we extensively peer review all stage and discharge measurements. These peer reviews ensure that measurement procedures were followed properly. Peer reviews also ensure that measurement results, supporting data, and observed conditions were determined correctly. We maintain quality assurance databases to document quantified measurement uncertainties and quality control findings for each discharge measurement. These databases are useful in evaluating the overall error in our measurements on a network-wide scale (Ecology 2021b).

10.3.1 Discharge measurement instrument quality control

10.3.1.1 Acoustic Doppler Velocimeters (ADV)

As discussed in 6.2.1.2, pre-measurement diagnostics are performed both in controlled and field environments to validate correct instrument function. A comprehensive Beam Check procedure conducted in a controlled setting tests and tracks the ADV probe prior to initial field deployments. In addition, a built-in quality control test (Automated Beam Check) is completed prior to every discharge measurement. Subsequent comprehensive beam checks are required when an instrument is damaged, repairs are made, firmware is upgraded, or after unexplained Automated Beam Check failures.

ADV automatically review a series of quality control parameters associated with each velocity measurement and provide a warning when parameter thresholds are exceeded. At the conclusion of the measurement, the ADV displays the overall calculated uncertainty of the measurement and its largest contributing source, velocity or depth. This measure of uncertainty serves as guidance to assign a preliminary quality rating for the measurement.

Avoiding all QC warnings for a particular discharge measurement is difficult and strictly dependent on the stream environment available. However, the feedback given by the ADV software allows the operator to address potential QC issues at the measurement site. Addressing QC warnings at the measurement site may require modification of the measurement cross-section, repeating velocity observations, adjusting the spacing of observations, adding observations to better define the channel, or choosing a different measurement cross-section (Ecology 2021a).

10.3.1.2 Teledyne RDI Acoustic Doppler Current Profilers (ADCP)

ADCPs also collect and process measurements in the field. We can identify most measurement problems during the measurement or through cursory reviews at the end of the measurement and take actions to correct them before the measurement is closed in the field (Ecology 2024a). Pre-measurement tests ensure proper functionality of ADCP systems, such as the integrated compass. These tests can identify the presence of a moving bed and other aspects of channel conditions that may affect measurement results.

QRev, an ADCP measurement processing program developed by the United States Geological Survey (USGS), independently automates the computation of discharge and provides further quality analysis for discharges measured with an ADCP. Ecology (2024a) provides additional guidance on the operation of the QRev utility and presents additional directions in the evaluation of ADCP measurements.

10.4 Corrective action processes

Streamflow monitoring program staff take corrective actions when activities or results are found to be inconsistent with measurement quality objectives.

10.4.1 Stage record corrections

The quality control objective for gage index discrepancies is to ensure that PGI and SGIs at station locations are observed correctly and that the observed values confirm the stage value determined by the stage sensor as recorded in the data logger. The threshold for the vertical movement of the PGI, triggering adjustment to the record, is 0.015 feet (Mastin 2017) as determined by differential leveling.

Multiple gage indexes are used to confirm stage or expose inaccuracies in the gage heights observed or measured from other gage indexes. All gage indexes at a station are relative to the gage datum, and observed water surface elevations should match. Sometimes, there are small differences in determined gage heights between the indexes because of streamflow or ambient conditions. However, if these differences persist, it could be because of vertical movement of one or more of the gage indexes. In order to minimize the impact of these differences across the stage records, it is important to address these issues as soon as possible.

Observed differences between the gage indexes greater than 0.02 feet at consecutive site visits should be investigated by the basin lead. Datum corrections, as determined by the results of differential leveling, are corrections applied to the stage record and rating curves compensating for the effects of movement of the PGI, since previous levels were run. These corrections assume an incremental movement of the PGI unless evidence supports that the movement occurred at a specific time.

If vertical movement of an SGI, greater than 0.015 feet, is determined by levels, we correct the elevation of the SGI such that it matches the PGI. It may be necessary to move the index structure to a new, more stable location to avoid further movement.

10.4.2 Discharge measurements

While conducting a wading-type of discharge measurement, corrective actions may include repeating individual depth/velocity measurements, adjusting the number and location of measurement verticals, or adding observations to better define the channel (Ecology 2021a). An ADCP measurement may require repeating or adding measurement transects. If the present cross-section does not yield a satisfactory measurement, it may be necessary to suspend and repeat the measurement using a different cross-section. In cases where deficiencies in the measurement render it unreliable and are not discovered until measurement processing, these can be flagged as discarded measurements.

In some instances, it is necessary to switch from an ADV to an ADCP, or vice versa, because conditions are not conducive to obtaining a satisfactory measurement, or QC feedback indicates poor performance with the equipment used to begin the measurement. It is permissible to suspend the measurement and switch instrument type. The objective is to use the correct instrumentation to yield the best quality measurement.

There are streamflow conditions where changes in the usual wading method measurement procedures are altered. When stage changes rapidly during a measurement, methods may be streamlined. For example, velocities are measured at 0.6 or 0.2 of depth regardless of depth, or velocity sampling times are reduced from 40 seconds to 20. The number of measured verticals is reduced from the usual 30 to 15 or 20. While some accuracy in the measurement may be lost, the error caused by the rapidly changing stage outweighs the loss of accuracy in a streamlined discharge measurement. These discharge measurement alterations are acceptable given rapidly changing stage conditions and documented in the SOP EAP056: Measuring and Calculating Stream Discharge (Ecology 2021b). In addition, a calculation method to determine stage when stage fluctuates rapidly during a discharge measurement is documented in the Standard Operating Procedure (SOP) (Ecology 2021b).

In the case of ADCP measurements in rapidly changing stage conditions, the only course of action is to reduce the measurement time, thus reducing the total number of reciprocal transects.

Another circumstance where it is necessary to deviate from standard procedure is when streamflow measurements are conducted in narrow channels (typically less than nine feet). This channel is not wide enough to measure depths and velocities at approximately 30 verticals. In all ADV or mechanical indicator measurements, the minimum width of measurement vertical is 0.30 feet; therefore, we measure as many verticals as possible to minimize the percentage of discharge in each measurement cell.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

The production of continuous streamflow discharge data made available in near real-time involves the ongoing synthesis of field-derived and telemetered data sources. These sources are analyzed and quality assured by the basin lead through our data management platform and reported to the publicly accessible [Freshwater DataStream](#)¹¹ application.

11.1.1 Field data management

Station data loggers observe and log stage data every 15 minutes, collecting a continuous record across the range of stage encountered during the water year or project duration. These data are transmitted to the program database at one-hour or three-hour intervals. At approximately six-week intervals, or about eight times a year, the basin lead downloads the stage data to a suitable storage device or through a cabled connection directly to a field computer (Ecology 2024b). These files are downloaded in text or CSV formats and viewed in either Microsoft Notepad or Microsoft Excel. Prior to uploading to the database, these raw files are stored in an Ecology network drive for the station and are kept as a backup.

Paper field notes associated with the observation of gage height and the status and condition of the gaging station infrastructure are collected on-site and checked for completeness prior to departure. They are then stored in temporary files managed by the station lead during manual entry to the database. Once the measurement has been entered into the database and has been peer reviewed, the field notes are moved to their permanent location in the file for that gage.

Discharge measurements conducted in the field generate paper field notes and digital files. The field notes are completed on-site and checked for completeness. The digital files generated during discharge measurements are typically in a proprietary format created by the manufacturer. They are then transferred from the device to the Ecology network drive for storage and post-processing.

Following each site visit, field notes for station infrastructure, the discharge measurement, and related gage height observation are entered into the data management platform for analysis and quality assurance. Discharge measurement files are post-processed in the manufacturer's proprietary software (QRev for Acoustic Doppler Current Profiler (ADCP) measurements) and uploaded to the database. All digital files and secondary post-processing files are stored in the Ecology network drive for the station. Once all the field notes have been entered and discharge measurements uploaded, they are submitted for peer review. Peer review involves both the paper field notes, the digital measurement files, and all associated data entry locations in the database.

¹¹ <https://apps.ecology.wa.gov/continuousflowandwq/>

11.1.2 Telemetry data management

Most streamflow monitoring stations are equipped with satellite telemetry. After stage data are logged (15-minute intervals) at the station, data are transmitted through the Geostationary Operational Environmental Satellite system (GOES) and received by Ecology in one-hour or three-hour segments. These data are decoded and ingested into the database as a telemetry file for that station. This file is the source of the near-real-time presentation of stage for each station on the Freshwater DataStream, prior to the retrieval of the station data from the field. This telemetry file is maintained as a backup, at least until data are retrieved from the station that covers the same period.

The use of telemetry is essential for continuous streamflow monitoring. It allows the basin lead to monitor the status of their station and its parameters remotely. This access to station status allows for any possible issues to be identified early, which minimizes the collection of poor-quality data and limits gaps in the continuous record or extended station downtime. If any issues or irregularities are identified, those issues can be communicated to the public via the station webpage and scheduled for repair as soon as possible.

11.1.3 Continuous discharge data reporting

During the water year, the Freshwater DataStream displays a combination of unchecked and provisional data, and it is the responsibility of the basin lead to maintain a schedule of field visits that serve to verify streamflow conditions that have occurred at the gage. In order to produce a continuous record of discharge from a station that transmits in near real-time, the basin lead must download the logged stage data from the datalogger on site and merge it with telemetered data in the data management software. These field visits and the best professional judgement of the interpretation of the field data inform the quality assurance of the telemetered data between visits.

Once the continuous stage data from the field is uploaded, a raw version is saved to the database. Then, the basin lead examines a separate copy of the continuous record for errors, gaps, and anomalous data points. Through this examination process, and especially if any adjustments are made, every 15-minute data point is assigned a quality assurance code, and comments describing the edits are made. During the field data entry process, the basin lead compares the observed height of the primary gage index (PGI) to the continuous stage record. If a difference exists (typically due to logger drift), a data shift is entered, which is applied incrementally, between visits, to adjust the continuous stage to observations of the PGI. After any adjustments and quality coding are complete, the stage data are archived and take the place of the raw telemetry data on the Freshwater DataStream.

The most complex ongoing task the basin lead must manage is the development of a discharge rating curve. This involves defining and maintaining over time a reliable mathematical relationship between field-measured discharge and observed gage height. This relationship can change over time, depending on the stability of gage reach control, and must be verified by

routine discharge measurements. All rating curves that are used during a water year are stored and applied in the data management platform.

After data processing and rating curve development, the continuous stage data are coupled with the active rating curve and displayed on the Freshwater DataStream application as near-real-time continuous streamflow. Any data transmitted through telemetry is initially provided to the public “unchecked,” but is subject to further review and verification through additional station visits.

As we progress through the water year with additional site visits and discharge measurements, the data entry and quality assurance coding procedures continue, with rating curves being updated or adjusted as necessary. Eventually, at the end of the water year, the result is a continuous record of discharge in provisional status, which is ready for submission to senior-level review and eventual final publication.

The Freshwater DataStream not only provides near-real-time stage and discharge information, but also makes historical data available to the public. The public has download access to 15-minute data tables, water year hydrographs, and tables of mean daily discharge, which include both monthly and annual statistics and related quality assurance codes.

The Environmental Information Management System database (EIM) Study ID for this project is FMUFLOW&WQ, but it is currently not in use. Historically, EIM did not have the capability to store the volume of continuous data generated under this project, hence the need for the Freshwater DataStream. Future efforts to store finalized streamflow discharge data, at a yet to be determined interval (15-minute, hourly, or daily), are currently being considered.

11.2 Laboratory data package requirements

Laboratory procedures do not apply to the work of streamflow monitoring activities.

11.3 Electronic transfer requirements

Laboratory procedures do not apply to the work of streamflow monitoring activities.

11.4 EIM/STORET data upload procedures

Procedures do not apply to the work of streamflow monitoring activities at this time.

11.5 Model information management

Procedures do not apply to the work of streamflow monitoring activities.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

12.1.1 Field audits

Senior hydrologists audit field staff every two years to confirm competency and adherence to the methods described in this document and associated Standard Operating Procedures (SOP) (see Table 8 in Section 6.2.2.1). The goal is to ensure methods used in the field align with written standard operating procedures. The Freshwater Monitoring Unit (FMU) supervisor approves the individual(s) responsible for training and audits.

During field audits, reviewers check the overall condition of the gage site and its components. Field procedures are evaluated. Reviewers assess stage determinations, measurement cross-section selection, and choice of measurement instruments. The discharge measurement is assessed for proper execution and use of equipment. Reviewers check that gage data are downloaded properly, and the gage is properly serviced with batteries and desiccant.

A written summary of the field trip, describing any necessary improvements or corrections, is provided to the basin lead and FMU supervisor.

12.1.2 Peer review of discharge measurements

All discharge measurement field notes and corresponding entries to the data management platform are peer reviewed. These reviews include verification that the correct measurement stage was determined, correct procedures and operation of equipment were followed, and descriptions of streamflow and channel conditions were noted. The peer reviewer makes sure that control conditions were identified and described, and that measurement parameters provided by the instrument software were properly documented in the field notes.

The initial quality rating of the measurement is evaluated for its consistency with the information provided in notes, instrument outputs, and measurement quality control summaries.

Entries to the database related to discharge measurements, gage index observations, and measurement notes are reviewed for completeness and accuracy. The reviewer assigns their initials in the space provided on the measurement note sheet and returns them to the basin lead. Any comments, recommended changes, or corrections are provided to the basin lead in writing. Discharge measurement entries to the data management platform are further evaluated during the senior-level review.

12.1.3 Other reviews

The results of differential levels operations are reviewed by senior staff following the compilation of level notes and worksheets. The reviewer ensures proper procedures were executed, calculations are correct, and carried out in order. The reviewer makes sure the closure error is within the limits of the calculated allowable closure error. All points in the

differential levels operation are evaluated for tolerable differences between the two surveyed elevations of each point.

Slope conveyance streamflow models are also reviewed by senior staff upon their completion. The reviewer makes sure the measurements used to develop the model apply to the model and are part of the same channel control stage-discharge relationship. The determined energy slope and Manning's roughness coefficient are checked for proper calculations and application. Reviewers also check comparisons between measured and modeled discharges, as well as model calibration, and calculated model confidence. Finally, model extrapolations are checked for fit on the rating curve.

12.2 Responsible personnel

Field audits are conducted by senior staff, such that each basin lead receives a ride-along audit every two years.

Basin leads are responsible for the peer reviews of discharge measurements. Measurement notes and associated documentation are submitted for review as soon as possible after processing the measurement.

Senior staff conduct reviews as soon as possible after the leveling procedure notes and electronic worksheets are processed.

Slope conveyance streamflow models are evaluated by senior staff after the model is developed.

12.3 Frequency and distribution of reports

All continuous stage and streamflow data, unchecked, provisional, and finalized, are accessible on the Freshwater DataStream application. The Freshwater DataStream also serves as a portal for the public to access current and historical data for both active and discontinued stations. The person can export a specific year of interest, or just as easily, the period of record at the station. In addition, individual or all parameters logged can be retrieved. The exported years and parameters of interest are automatically compressed into a zip file that is downloadable directly from the application at any time.

As outlined in section 5.4 (Table 5), the basin lead aims to finalize the continuous record of streamflow within one and a half years following the end of the water year (WY). In addition to the finalization of the continuous records, beginning with WY 2005, basin leads are required to produce a Stream Discharge Technical Note for each WY. This document is also publicly available on the Freshwater DataStream and is included in the data export for a finalized WY.

The Stream Discharge Technical Note (Appendix B) provides a more in-depth description of the streamflow monitoring station and the conditions for the year. It begins with a watershed description, including the predominant land use, topography, annual rainfall, and drainage area above the gage. It provides a detailed description of the gage location, including coordinates

and the placement of the gaging station infrastructure. A table of discharge statistics, with additional attributes not available in the mean daily discharge table, is discussed and summarized. Unique to this document, the basin lead provides the results of the automated error assessment and discusses the sources that lead to the potential error due to logger drift and weighted rating curve error. In addition, the basin lead provides a summary of the range of stage experienced at the gage and any notable high or low streamflow events. The document continues with a summary table and discussion detailing the rating curves used, their period of application, and the potential error of each. Finally, the document concludes with a discussion of any high streamflow models used to extend the publishable range of discharge, any surveys conducted, and notable activities completed during the WY.

12.4 Responsibility for reports

The Basin or individual station lead is responsible for all reporting and publishing of continuous stage and streamflow, including Stream Discharge Technical Notes, for a monitoring station in a water year. The technical notes are reviewed for content and accuracy by the senior-level reviewer and are proofread for grammar and accessibility by the second senior-level reviewer prior to publication directly to the Freshwater DataStream.

13.0 Data Verification

Streamflow data verification begins with discrete observations of stage and discharge measurements in the field, proceeds through peer reviews, and is finally subject to a comprehensive senior-level review of all aspects of the record. These activities (quality checks, tests, and documented procedures designed to ensure development of the highest possible quality streamflow record) are described throughout this document or in the more detailed standard operating procedure documents.

Streamflow data are considered verified and final after a comprehensive review is completed.

13.1 Data processing and analysis

13.1.1 Quality code assignments

Monitoring program staff use a system of quality code assignments that serves to verify the data by categorizing it based on the level of confidence and status of the data. These quality codes collectively express the level of confidence in the individual components comprising the overall streamflow record. Refer to the list of quality codes in Table C-1 in Appendix C.

The Freshwater DataStream presents discharge data coded with a quality assignment. The quality assignment provides the data consumer with the level of confidence in data quality, the status of the data, and, to the extent possible, some explanation for the assigned quality code.

There are four basic categories of confidence in stage data collected:

- *Good data*, with high confidence in the reliability of the data.
- *Estimated data*, with some uncertainty in the validity of the data.
- *Questionable estimated data*, higher level of uncertainty, but still displayed and published.
- *Unreported*, very low confidence, or known erroneous data. Will not report on the Freshwater DataStream or be published in final records.

There are three basic quality statuses of continuous telemetered stage data:

- *Data not yet checked*. Data has not been analyzed or reviewed at any level. Data are checked within three weeks of downloading from the logger.
- *Provisional data*. Preliminarily reviewed by the basin lead, the data set is thought to be reliable but subject to change and updates. Quality assignment can change.
- *Finalized data*. Data has been reviewed at the senior-staff level.

Basin leads assign quality codes to every logged stage data point, gage-height observation, rating curve point, and discharge measurement. Several factors go into the assignment of a stage record quality code, including the confidence of primary gage index (PGI) readings, which serve as the basis for the stage record. Other factors include whether the gage index was

observed directly and verified by direct observation of the secondary gage index (SGI) or estimated and calculated based only on observations of the SGI due to damage or inundation of the PGI.

Quality codes are also applied when data are imported from another gage because of damage or malfunction of the logger or stage sensor. Ice in the winter months, particularly in eastern Washington, may affect confidence in the continuous stage record. There are many other factors that may influence confidence in the continuous data record for which quality codes are assigned.

Rating curves also have a system of quality code assignments. Rating table points, which consist of stage and discharge value pairs that comprise the rating curve, are assigned quality codes. The quality of these points is used to determine the quality and reliability of rating curves and the published discharge. These rating table points are coded as follows:

- *Unknown flow*, Discharge is less than half the value of the lowest measured discharge, with no point of zero flow (PZF) measured.
- *Below rating curve, reliable extrapolation*: Associated stage is below the measured range of the rating curve, but reliable and displayed or published on the Freshwater DataStream.
- *Measured range of rating curve*: The stage range from the lowest measured discharge to the highest measured discharge in the active rating curve period.
- *Above rating curve, reliable extrapolation*: Associated stage is above the measured range of the rating curve but within two times the value of the highest measured discharge.
- *Rating curve exceeded*: Where the associated stage is greater than two times the highest measured discharge and not displayed or published on the Freshwater DataStream.
- *Modeled*: Discharges exceeding the rating curve may be modeled using the slope-conveyance high streamflow model. The modeled portion of the rating curve is assigned this code to indicate that those discharge values are derived from the model. Secondary qualifiers may also be assigned to describe the quality of the modeled discharge.

Discharge measurements are also assigned a code based on the quality assignment of the measurement discussed in section 8.2.2 of this document. The quality designation assigned to discharge measurements informs the value of quality codes assigned to rating curve points.

The daily mean stage record is assigned its quality code based on the poorest quality category assigned to any 15-minute data point throughout the day. Stated alternatively, the assigned daily quality code can be no higher than the poorest quality category assigned to any 15-minute data point during the day. The same concept applies to the quality code assigned to the annual stage data set. This quality assignment also reflects the poorest quality assigned in the entire 15-minute data set comprising the whole year.

Quality codes assigned to the streamflow record incorporate quality assignments from both the stage record and the code assigned to the rating curve points. Daily and annual mean streamflow records reflect the poorest quality assignment between the rating curve and the stage record.

13.1.2 Sensitivity drift analysis

As part of the data verification process, the basin lead analyzes instrument drift using linear regression between correction values applied to the stage record based on gage-height observations and the corresponding stage in the logger record. This action is performed to determine whether the stage record exhibits sensitivity drift. Recall from Section 6.1.1, sensitivity drift is a type of drift where the differences between true gage heights and instrument outputs change linearly over time. Sensitivity drift, identified by running regression analysis across contiguous differences between the corrected stage record and gage index observations, exhibits a clear pattern in the data, trending either upward (positive drift) or downward (negative drift) as stage increases or decreases, with a strong correlation ($r \geq 0.80$) between corrected stage and data shift.

If sensitivity drift is found at a station, we use the results of the stage vs. correction values regression to derive a “drift curve” that varies the magnitude of drift by stage height. Steps for correcting sensitivity drift in a data set are detailed in Appendix A of SOP EAP082, *Correction of Continuous Stage Record Subject to Instrument Drift* (Ecology 2022d).

13.1.3 Streamflow record error analysis

The streamflow monitoring program senior staff developed an automated error analysis application that quantifies estimated potential error for all three data quality objectives (refer to section 6.1). The application directly calculates uncertainty in the two major components comprising a continuous streamflow record: the rating curve and stage record, and is reported as total potential error. We derive the total potential error by summing the uncertainties in the rating curve and the stage record.

First, we consider a phenomenon known as stable drift. Stable drift reflects a consistent difference between observed gage height and logged stage values. Neglecting to address stable drift can result in substantial inaccuracies in potential error determinations as well as inappropriate data quality assignments.

13.1.3.1 Stable drift error analysis

Stable drift occurs when the difference between logged stages and PGI observations remains steady and nearly equal.

We define stable drift as a set of two or more contiguous differences between logger recordings and gage height observation pairs where the range of differences between the highest and lowest exceeds no more than 0.03 feet and the standard deviation of the differences does not exceed 0.015 feet.

The automated error analysis identifies and computes stable drift errors and applies the mean stable drift error percentage to the entire period of daily mean discharges identified in the comparative drift-error analysis.

Stable drift error in the corrected stage record is calculated in the following form:

$$U = \frac{\sum_{i=1}^n \left| \left(\frac{x-y}{x} \right) \right|_i}{n} * 100$$

Where:

U = mean error for the stable drift period expressed in percent

x = discharge corresponding to an observed gage height in cfs

y = discharge corresponding to offset logger value in cfs

n = number of x and y pairs in the stable drift period.

Offset logger value in the above equation is expressed in the form:

$$\emptyset = r - \frac{\sum_{i=1}^n (r - g)_i}{n}$$

Where:

$\emptyset$ = offset logger value (in feet)

r = raw logged stage value (in feet)

g = observed gage height value (in feet)

n = number of r and g pairs in stable drift period.

13.1.3.2 Stage record error analysis

We determine uncertainty in the stage record by calculating the differences in daily mean predicted discharge values computed from separate corrected and uncorrected stage records. Corrected discharge records are derived from stage records corrected based on field gage height observations, then coupled with the corresponding rating curve, producing a corrected discharge record. An uncorrected discharge record consists of an uncorrected stage record—the raw stage record that has not been corrected to reflect stage observations. We consider the calculated differences between daily mean discharge values as the potential error.

Potential error in the corrected stage record is calculated in the following form:

$$S_e = \frac{\sum_{i=1}^n \left| \left(\frac{y-x}{x} \right) \right|_i}{n} * 100$$

Where:

S_e = the absolute value of the percent error between the daily mean discharge derived from the corrected stage record and the discharge computed using the uncorrected record

x = mean daily discharge from the corrected stage record in cfs and

y = mean daily discharge from the uncorrected stage record in cfs.

n = number of x and y pairs in stage record error analysis period

The error analysis application guides quality assignments to the stage record by flagging daily mean discharges as good data, an estimate, a questionable estimate, or data not published.

Table 10. Quality codes are assigned to data sets based on a tiered approach.

Tier	% Diff ^a	Conjunction	Diff Q ^b	QC ^c
1	0–20%	OR	<0.5	Good Data
2	≥20%	AND	≥0.5	Estimated Data
3	≥50%	AND	≥5	Questionable Estimate
4	≥100%	AND	≥50	Data Not Published

^a Percent Difference

^b Difference in Discharge (Q)

^c Quality Code

Table 10 illustrates how quality assignments derived from the error assessment application are determined using a tiered approach, whereby the difference (*Diff Q*) and percent difference (*% Diff*) between raw and adjusted daily mean discharge values are used to determine the appropriate quality assignment (Ecology 2022d).

When the maximum potential percent error (e in the equation above) for daily mean discharges exceeds 20 percent, and the differences in discharge between corrected and uncorrected stage records exceed 0.5 cfs, these daily mean discharges are flagged as estimated data. When the potential error is greater than 50 percent and the differences between corrected and uncorrected records exceed 5 cfs, discharges are qualified as questionable estimates. The

program does not publish discharges where the potential error exceeds 100 percent, and differences between the two records exceed 50 cfs (Ecology 2022d).

13.1.3.3 Rating curve error analysis

To assess the quality of a rating curve, we determine its uncertainty by computing the percent difference between measured discharges and the discharges predicted by the rating curve. We adjust this calculated uncertainty to the maximum potential error by adding the assigned error percentage associated with the quality assignment of the measurement determined by the basin lead. This represents the largest potential difference between the measured discharge and the discharge predicted by the rating curve (Ecology 2022d).

Potential error in the rating curve is calculated in the following form:

$$R_e = \frac{\sum_{i=1}^n \left| \left(\frac{Q_{pred} - Q_{adj}}{Q_{adj}} \right) \right|_i}{n} * 100$$

Where:

R_e = average percent differences over the period of a rating between the predicted discharge values and adjusted measured discharges.

Q_{pred} = The discharge predicted by the rating curve in cfs

Q_{adj} = the measured discharge value with measurement error estimate added or subtracted in cfs

n = number of Q_{pred} and Q_{adj} pairs.

Adjusted measured discharge (Q_{adj}) is calculated in the following form:

$$Q_{adj} = Q_{meas}(1 \pm P_e)$$

Where:

Q_{adj} = the measured discharge value with measurement error estimate added or subtracted in cfs

Q_{meas} = the measured discharge value in cfs

P_e = estimated error percentage assigned to the measurement. Note: error is added to the measured discharge value when predicted discharge is less than the measured discharge, and subtracted when predicted discharge is greater than the measured discharge.

13.1.3.4 Total potential error

To determine total potential error, we sum the potential error in the stage record and the potential error in the rating curve. Our overall data quality objective is to limit total potential error in continuous streamflow records to 15%.

Total potential error in the record is calculated using the following equation:

$$T_e = S_e + R_e$$

Where:

T_e = total potential error in the streamflow record

S_e = the absolute value of the percent error between the daily mean discharge derived from the corrected stage record and the discharge computed using the uncorrected record

R_e = percent difference between the predicted discharge value and the adjusted measured discharge.

To correctly calculate potential error through the automated error analysis application, we exclude erroneously logged data due to instrument damage, low battery voltage, anomalous spikes, channel icing, and other similar circumstances precluding the use of logged data. Also excluded from the drift analysis are data from another station imported to fill periods of missing or erroneous data. While certain circumstances, such as backwater conditions, may still produce a correct record of gage height, in the absence of a valid stage-discharge relationship, the error calculations will be incorrect, as will predicted discharge.

13.2 Field data verification, requirements, and responsibilities

The goal of the senior-level review process is to ensure the accuracy and reliability of streamflow records by evaluating the data and assessing whether the measurement quality objectives defined in section 6.2 were met.

13.2.1 Senior-level review of finalized records

Senior staff comprehensively examine streamflow records for completeness and accuracy. Station notes are thoroughly reviewed. Supporting files and documentation are reviewed.

The review process is conducted in three broad phases:

- Records review: Consists of a rating curve review and stage record review.
- Error analysis review: Review the level of determined uncertainty in the streamflow record.
- Technical note review: Review for the accuracy of tables and narratives presentation.

Rating curves are checked to ensure they are viable and developed correctly. The review of the rating curve ensures quality codes in the rating table are correctly assigned and confirms the degree to which the rating curve covers the range of the stage record for the rating curve period. Transitions between rating curves are reviewed. It is often difficult to distinguish when or the length of time during which transitions between rating curves take place. The reviewer

also checks that discharge measurements defining the rating curve (measurements on which the development of the rating curve is based) are correctly identified.

The reviewer ensures that actions taken to correct the record were done correctly and follow proper procedure. Transcribed field notes are reviewed. Notes describing rating curve development are reviewed. The correct application of quality codes is checked. Supporting files and documentation are reviewed.

Senior-level reviews also involve making sure stage observations and discharge measurements are obtained following proper procedures, within acceptable thresholds, and meet the quality objectives described in section 6.2 and shown in tables 6 and 7. The review examines actions taken to minimize bias in measurements, steps taken to ensure the streamflow record is representative of conditions in the watershed, and completeness of the record.

All streamflow data are considered provisional and subject to change before completion of the final records review. All records comprising the water year are considered final when water-year reviews are completed. The technical note document corresponding to each water year presents annual streamflow information, including mean daily discharges, median discharge for the year, and maximum and minimum discharges. The range of the stage record is also presented. Also documented in the technical notes are the results of the error analysis and descriptions of the gage location and basin area. Notable streamflow events occurring throughout the year are discussed. Details of rating curves used throughout the year are described, including the calculated potential error associated with each rating curve.

Records reviews are presented in electronically written form and discussed with the responsible basin lead. Identified problems in the record are addressed by the basin lead to the satisfaction of the senior-level reviewer. The electronic documentations of the review are retained on Ecology servers. The reviewer facilitates the transition of the records from provisional to final and the publication of technical notes.

13.3 Laboratory data verification

Procedures do not apply to the work of streamflow monitoring activities.

13.4 Validation requirements, if necessary

Procedures do not apply to the work of streamflow monitoring activities.

13.5 Model quality assessment

Procedures do not apply to the work of streamflow monitoring activities.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

Streamflow and stage data generated by the monitoring program, due to its continuous nature for data collection and transmission, are frequently assessed for usability or reportability to the Freshwater DataStream. At six-week intervals, the basin lead follows, which is confirmed by peer review, protocols established in this QAMP, and standard operating procedures to verify the accuracy and quality of the telemetered continuous data. On an annual basis, through the senior level review process (Section 13.1), the senior level reviewer assesses all water year records, measurements, and observations generated at a station to determine if project objectives were met and whether the data can be finalized.

The Freshwater Monitoring Unit (FMU) supervisor oversees all streamflow monitoring activities, including the development of field procedures and quality assurance workflows by senior staff and the Stream Hydrology Technical Coordination Team. The FMU supervisor also evaluates the overall timeliness and accuracy of the continuous stage and discharge publishing and examines the results of the senior-level review process. This allows them to assess overall data quality at the network level and to identify areas of continued improvement or the need for efficiencies throughout the streamflow monitoring program activities performed by the FMU.

Through the review process, it may be discovered that a gage or its infrastructure was poorly located, or other problems resulted in a large percentage of Measurement Quality Objectives (MQO) not being met. If these circumstances arise, the basin lead, senior-level reviewer, and the FMU supervisor will meet to determine if additional work could recover the dataset within a reasonable time frame. If not, the tough decision is made to reject or not publish that water year.

14.2 Treatment of zero streamflow and unreported days

During a water year, depending on site conditions, the extent of the reportable range of discharge, or through the application of quality assurance codes, the resulting value of streamflow can be zero or unreported. These values, or lack thereof, can influence water year summary statistics.

Though the proper siting of a monitoring station should limit the occurrence, the extreme lack of precipitation (or snowmelt) over an extended period could result in zero streamflow passing the gage, particularly in smaller streams. Alternatively, through multiple scenarios, such as rating curve exceedances or extreme instrument drift, the basin lead may choose to qualify data values as unreported. This case results in what is considered a missing value or day.

In the context of water year summary statistics, where it has been confirmed by the basin lead that a waterbody truly became dry or no water was passing the gage, the value of zero is included in statistical results. Because of assigned quality assurance codes, some data points

comprising a daily mean discharge will not be calculated, causing the entire day to not report to the Freshwater DataStream. However, that missing day does not prevent the display or publishing of monthly or annual statistics. It is the responsibility of the basin lead to discuss the cause of any unreported days, how many there are, and to what degree they may impact water year statistics in the Stream Discharge Technical Notes.

14.3 Data analysis and presentation methods

In terms of data presentation, the [Freshwater DataStream](#)¹² provides a display of near real-time continuous stage and discharge hydrographs (including any water quality parameters) which are available for active streamflow monitoring stations. These parameters are accessed via tabs for “Flow” and “Stage” from the Station Information page for each station. They are displayed both on a seven-day scale and for the water year, which expands as it progresses through the year. Discharge measurements and stage quality assurance observations are also displayed on the same hydrograph. Below the hydrographs, the Mean Data table for the current year with daily, monthly, and annual statistics is displayed. An example of the mean data table is presented in Appendix D. Scrolling further, individuals have access to a 15-minute data table, which displays the telemetered values (stage and discharge), and the quality assurance code applied to each timestamp. Finally, at the bottom of the page, all the historical data for the gaging station’s period of record is available and sorted by water year. A water hydrograph, mean data table, mean daily table, and 15-minute data table are available for each year. In addition, if the records are finalized for that year, a graphic of a single representative rating curve, a tabular output (rating table) of the representative rating curve, and Stream Discharge Technical Notes can be accessed. As discussed in section 12.3, all data can also be exported for download.

On the Freshwater DataStream, statistics are available for the current water year and for previous years. Refer to Appendix D for a link to an example of a Mean Data table. This table displays (for stage and discharge separately) instantaneous minimum and maximum (min/max) for the month and year, daily mean, min/max daily mean for the month and year, monthly mean and median, and finally annual mean and median. This auto-generated statistical summary from the data management platform also tracks the missing days for the month and year. In addition, under the “Notes” section is a list of the applied quality assurance codes. As the water year progresses, the relevant statistics update daily. Any updates to unreviewed historical data are applied to the Freshwater DataStream on a weekly schedule. When the streamflow records are finalized, this information is locked.

Streamflow monitoring data for historical or otherwise discontinued gages can also be accessed through the Freshwater DataStream. This subset of gages can either be manually turned on using the layer controls on the statewide map, or while looking at a Station Information page and toggling the “Historical” button above the list of active gaging stations for a Water

¹² <https://apps.ecology.wa.gov/continuousflowandwq/>

Resource Inventory Area (WRIA). Once a historical station is accessed, the structure of that page is identical to what was described above for active stations.

Most of the data compilation, analysis, and review are conducted within the monitoring program's data management platform. As was mentioned in section 6.3, since 2003, we have been using Hydstra, which is comprised of a comprehensive suite of time-series, discrete observation, rating curve development, statistics, and data publishing modules. At the time of writing this QAMP, we are in the process of seeking a replacement for our data management platform that will better fit our modern business needs.

In addition, we use ancillary applications to supplement our data management platform, such as an MS Excel-based application (BARC) to assist with rating curve development acquired from the United States Geological Survey (USGS). Most notably, however, we use an in-house developed error assessment application described in section 13.0 to analyze and compute the potential error in the continuous streamflow record. We document this potential error in written, publicly accessible technical notes as described in section 12.3.

There are two locations where general statistics are made available to the public: the Freshwater DataStream and the Stream Discharge Technical Notes (Appendix B). These statistics are either auto-generated through the data management platform's statistics reporting modules or the error assessment application. Below is a list of annual streamflow record statistics and attributes found in the Stream Discharge Technical Notes:

- Mean annual discharge (cfs)
- Median annual discharge (cfs)
- Maximum daily mean discharge (cfs)
- Minimum daily mean discharge (cfs)
- Maximum instantaneous discharge (cfs)
- Minimum instantaneous discharge (cfs)
- Discharge equaled or exceeded 10% of recorded time (cfs)
- Discharge equaled or exceeded 90% of recorded time (cfs)
- Days discharge is greater than the range of rating curves
- Days discharge is less than the range of rating curves
- Un-reported days
- Days qualified as estimates
- Modeled days
- Potential logger drift error (Percent of discharge)
- Potential weighted rating curve error (Percent of discharge)
- Total potential error (Percent of discharge)
- Minimum recorded stage (feet)
- Maximum recorded stage (feet)
- Range of recorded stage (feet)

- Number of rating curves
- Date range of rating curve periods
- Range of rating curves (cfs)
- Number of defining discharge measurements
- Individual rating curve error (percent)

14.4 Sampling design evaluation

The streamflow monitoring program is a multi-year, ongoing activity with most gages. Except for some temporarily installed gages in support of time-defined research projects and studies, most gages are established for the long term. The streamflow gaging program's sampling design is mainly geared toward assessing current streamflow conditions, evaluating long-term trends, and establishing historical baselines for use in future research.

The FMU supervisor is ultimately accountable for ensuring that the data generated and reviewed meet the MQOs, as well as criteria for completeness, representativeness, and comparability. The FMU supervisor also determines whether summary statistics support conclusions regarding monitored streamflow. If the manager determines these objectives have been met, the sampling design is considered effective.

14.5 Documentation of assessment

The senior-level review of annual streamflow data serves as the data usability assessment for the generated data. Notes of the findings in the data review, including corrective actions taken by basin leads, are documented and preserved.

Additionally, notes in the database entered by the basin lead documenting actions and decisions made while developing the record are preserved. Original handwritten station notes, as well as discharge measurement and levels operation notes, are also archived.

15.0 References

- Benson, M.A., and T. Dalrymple. 1967. General Field and Office Procedures for Indirect Discharge Measurements. Techniques of Water Resources Investigations of the United States Geological Survey, Chapter A1, US Government Printing Office, Washington, D.C. <https://pubs.usgs.gov/publication/twri03A1>
- Blanchard, S.F. 2010. Independent Water Temperature Measurement for Hydroacoustic Measurements. United States Geological Survey, Office of Surface Water. Technical Memorandum 2010.07. <https://water.usgs.gov/water-resources/memos/memo.php?id=579>
- Chapter 90.03 RCW. Water Code. Revised Code of Washington. <https://app.leg.wa.gov/rcw/default.aspx?cite=90.03>
- Ecology [Washington State Department of Ecology]. 2021a [Recertified/Not Published]. Standard Operating Procedure EAP058, Version 2.0: Measuring Stream Discharge using SonTek® Acoustic Doppler Velocimeters. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2021b [Recertified/Not Published]. Standard Operating Procedure EAP056, Version 1.4: Measuring and Calculating Stream Discharge. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2022a [Recertified/Not Published]. Standard Operating Procedure EAP072, Version 2.2: Basic Use and Maintenance of WaterLOG® Data Loggers and Peripheral Equipment. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology] 2022b [Recertified/Not Published] . Standard Operating Procedure EAP057, Version 1.3: Conducting Stream Hydrology Site Visits. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2022c [Recertified/Not Published]. Standard Operating Procedure EAP042, Version 1.3: Measuring Gage Height of Streams. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2022d. [Recertified/Not Published]. Standard Operating Procedure EAP082, Version 1.3: Correction of Continuous Stage Records Subject to Instrument Drift. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>

- Ecology [Washington State Department of Ecology]. 2023a [Recertified/Not Published]. Standard Operating Procedure EAP059, Version 1.4: Operation of Mechanical Velocity Indicators. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2023b [Recertified/Not Published]. Standard Operating Procedure EAP060, Version 2.3: Measuring Stream Discharge from a Bridge Using Mechanical Equipment. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2024a [Recertified 2022]. Standard Operating Procedure EAP055, Version 2.1: Operation of the Teledyne RD Instruments RiverPro Acoustic Doppler Current Profiler. Publication 24-03-201. Olympia, WA. <https://apps.ecology.wa.gov/publications/SummaryPages/2403201.html>
- Ecology [Washington State Department of Ecology]. 2024b [Recertified/Not Published]. Standard Operating Procedure EAP089, Version 1.0: Basic Use of Sutron® SatLink 3 Logger. Olympia, WA. For a copy of this document, please submit a request by visiting <https://ecology.wa.gov/publicrecords>
- Ecology [Washington State Department of Ecology]. 2024c [Recertified 2024]. Standard Operating Procedure EAP070, Version 2.4: Minimizing the Spread of Invasive Species. Olympia, WA. <https://apps.ecology.wa.gov/publications/SummaryPages/2403204.html>
- Elsner, M.M., Cuo, L., Voisin, N., Deems, J., Hamlet, A.F., Vano, J.A., Mickelson, K.E.B., Lee, S-Y., Lettenmaier, D.P. 2009. Implications of 21st century climate change for the hydrology of Washington State. Chapter 3.1 in *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*. Climate Impacts Group, University of Washington, Seattle, Washington. <https://cig.uw.edu/publications/implications-of-21st-century-climate-change-for-the-hydrology-of-washington-state/>
- Freeman, L., M. Carpenter, D. Rosenberry, J. Rousseau, R. Unger, and J. McLean. 2004. Use of Submersible Pressure Transducers in Water-Resources Investigations: Chapter A of Book 8, Instrumentation Section A: Instruments for Measurement of Water Level. United States Geological Survey, Publication. <https://pubs.usgs.gov/publication/twri08A3>
- Gunn, M.A., Matherne, A.M., and Mason, R.R. 2014. The USGS at Embudo, New Mexico: 125 years of systematic stream gaging in the United States. US Department of the Interior, US Geological Survey. <https://doi.org/10.3133/fs20143034>.
- Kenney, T.A. 2010. Levels at Gaging Stations: U.S. Geological Survey Techniques and Methods, Book 3, chap. A19, 60 p. <https://pubs.usgs.gov/publication/tm3A19>

- Mastin, M.C., 2017. Surface-water quality-assurance plan for the U.S. Geological Survey Washington Water Science Center (ver. 1.1, August 2017): U.S. Geological Survey Open-File Report 2016–1020, 85p.
<https://pubs.usgs.gov/of/2016/1020/ofr20161020.pdf>
- Mueller, D. S., C. R. Wagner, M.S. Rehm, K. A. Oberg, and F. Rainville. 2013. Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat, version 2.0, December 2013. U.S. Geological Survey Techniques and Methods, book 3, chapter A22, 95 p.
<https://pubs.usgs.gov/tm/3a22/>
- NOAA [National Oceanic and Atmospheric Administration]. 1985. Narrative Summaries, Tables and Maps for Each State with Overview of State Climatologist Programs, Third Edition; Volume 2: New York-Wyoming, Gale Research Company. Accessed: 12/14/2023
https://wrcc.dri.edu/Climate/narrative_wa.php
- Rantz, S.E., et al. 1982. Measurement and Computation of Streamflow: Volume 1 and 2. Measurement of Stage and Discharge. United States Geological Survey Water-Supply Paper 2175.
<https://pubs.usgs.gov/publication/wsp2175>
- SonTek/Xylem, Inc. 2024. FlowTracker2 User’s Manual 2.0, Software Version 2.0, Firmware Version 1.3, 45–0120 Rev L.
- WAC 173. Department of Ecology. Chapters 500-564. Washington Administrative Code.
<https://apps.leg.wa.gov/Wac/default.aspx?cite=173>

16.0 Appendices

Appendix A. Freshwater DataStream Station Addresses

Table A-1. List of Freshwater DataStream application website addresses.

Map #	Station I.D.	Address
1	01C070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=01C070
2	01N060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=01N060
3	01Q070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=01Q070
4	03C060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=03C060
5	03G100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=03G100
6	03J100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=03J100
7	05A070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=05A070
8	05A105	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=05A105
9	05B090	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=05B090
10	05B110	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=05B110
11	05D070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=05D070
12	07A090	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=07A090
13	17B050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=17B050
14	17D060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=17D060
15	17E060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=17E060
16	17F050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=17F050
17	17G060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=17G060
18	18A050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18A050
19	18C150	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18C150
20	18F250	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18F250

Map #	Station I.D.	Address
21	18H250	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18H250
22	18J250	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18J250
23	18K250	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18K250
24	18P070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18P070
25	18R250	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=18R250
26	19H080	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=19H080
27	19J100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=19J100
28	20A070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=20A070
29	22D110	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=22D110
30	23B190	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23B190
31	23C070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23C070
32	23E060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23E060
33	23H060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23H060
34	23I070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23I070
35	23J070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23J070
36	23K060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=23K060
37	24N070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=24N070
38	25B060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=25B060
39	25C060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=25C060
40	26B080	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=26B080
41	28B080	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=28B080
42	29C100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=29C100
43	32A090	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32A090

Map #	Station I.D.	Address
44	32A100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32A100
45	32A105	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32A105
46	32A120	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32A120
47	32B075	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32B075
48	32B090	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32B090
49	32B100	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32B100
50	32D060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32D060
51	32E050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32E050
52	32K070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=32K070
53	SPRAD1	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=SPRAD1
54	35B150	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=35B150
55	35K050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=35K050
56	38G150	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=38G150
57	39D110	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=39D110
58	39J070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=39J070
59	39M130	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=39M130
60	39P080	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=39P080
61	39S050	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=39S050
62	45B070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=45B070
63	45E070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=45E070
64	45F070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=45F070
65	45J070	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=45J070
66	48F060	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=48F060

Map #	Station I.D.	Address
67	48F150	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=48F150
68	LOOST1	https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=LOOST1

Appendix B. Example of Stream Discharge Technical Note

Freshwater DataStream Link to an example of a Stream Discharge Technical Note:

https://apps.ecology.wa.gov/continuousflowandwq/StationData/Prod/05A105/05A105_2022_TECH.PDF

Appendix B is available online and is linked to this report at

<https://apps.ecology.wa.gov/publications/SummaryPages/2503106.html>.

Appendix C. Quality Codes

Table C-1. List of Freshwater Monitoring Unit Streamflow Quality Codes.

Quality Code Number	Text Description
1	Good quality REVIEWED data
2	Good quality provisional data
3	Good quality provisional data — edited
8	Below rating curve, reliable extrapolation
10	Above rating curve, but within 2x, reliable extrapolation
13	Flow measurement rating = Excellent
14	Flow measurement rating = Good
15	Flow measurement rating = Fair
20	Flow measurement rating = Poor
30	Irregular Time Rate Data — weekly/monthly read.
40	Significant stage change during flow measurement
45	Data filtered to remove excessive noise
50	Estimated data
75	Reference station data
77	Correlation with other station, same variable

Quality Code Number	Text Description
78	Correlation with other station, different variable
82	Linear interpolation across gap in records.
90	Data Generated by cooperator (not ECY)
100	Modeled flow
140	Data not yet checked
151	Data Missing
160	Above rating, over 2x
161	Below rating, less than 1/2x
162	Modeled flow — calibrated results exceed 20% of measured flow
163	Non-FMU flow measurement — Will report
164	Questionable estimate
165	Below instrument threshold*
166	Point of Zero Flow (PZF)*
179	Estimated data — unreliable*
180	Modeled flow - calibrated results exceed 35% of measured flow*
200	Raw file data excluded from drift analysis*
201	Data not recorded*
210	Non-FMU flow measurement*
215	Data Rejected*
220	Backwater flow conditions*
225	Flow measurement discarded*

Quality Code Number	Text Description
230	Instrument impaired*
240	Instrument damaged*
250	Ice impacted data*
252	Bankfull discharge exceeded*
254	Rating table exceeded (data will not be reported)*

* Data with this quality code will not report to the Freshwater DataStream

Appendix D. Example of Mean Data table

Freshwater DataStream Link to an example of a Mean daily streamflow table:

https://apps.ecology.wa.gov/ContinuousFlowAndWQ/StationData/Prod/05A105/05A105_2022_DSG_MD.txt

Appendix E. Glossaries, Acronyms, and Abbreviations

Glossary of general terms

ADCP: An Acoustic Doppler Current Profiler emits sound pulses into water bodies. By measuring the Doppler shift from signals reflected off particles in the water and the stream bottom, the ADCP determines water velocity, depth, and the speed of the instrument over the bottom. Stream discharge is determined from these measurements.

ADV: An Acoustic Doppler Velocimeter measures stream velocity by sensing the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow of water.

Basin Lead: Primary hydrologist or scientist, responsible for the overall operation and data management of a stream gage.

Bottom Tracking: Bottom tracking measures the ADCP's speed over the stream bottom as well as water depth.

Boundary: An underwater obstacle that impedes the transmission or receipt of the acoustic signal by the FlowTracker. The sampling range self-adjusts to some boundaries but may dramatically reduce the observed maximum velocity.

CFS: The volume of water in a stream passing a given point at a given moment in time expressed as cubic feet per second.

Control: The physical features of a stream that control the relationship between stage and discharge at a gage site.

Cross Section: The measurement cross-section is a vertical plane extending from either stream edge, up from the stream bottom to the surface.

Discharge: The volume of water in a stream passing a given point at a given moment in time and is determined by measuring the stream channel cross-sectional area and the water's mean velocity at the site selected.

Drift: An undesired change in instrument output over time, not a function of real changes in water surface elevation (stage).

Ensembles: An ensemble is a vertical profile of velocity created by the RiverPro. Ensembles are expressed in WinRiver II contour graphs as a series of columns extending across the transect. Each ensemble contains a "stack" of depth cells (bins). The width and number of ensembles in a transect is determined by vessel speed and cross-section width.

ft/s: Velocity of water expressed in feet per second.

Gage Datum: The term datum in the context of this document refers to the elevation plane to which all reference marks, reference points, and water surface elevations are determined. At streamflow monitoring stations, the datum is set below the elevation of zero flow and maximum scour.

Gage Height: Often, this term is used interchangeably with stage. However, gage height is more appropriately used to indicate the water surface observed on a particular gage index.

GOES: The Geostationary Operational Environmental Satellite system is the National Oceanic and Atmospheric Administration (NOAA) operated satellite system that FMU radios transmit stage and other environmental data. The data are received by the NOAA data acquisition center at Wallops Island, Virginia, from which the data are disseminated to Ecology for processing and presented on Ecology's Freshwater DataStream.

Hyporheic Flow: Sometimes referred to as underflow, movement of water in the area beneath and adjacent to a stream where surface water and groundwater intermix.

Laser Beam Elevation: The elevation of the plane of the laser beam emitted by the laser instrument. The height of the beam emitted from the instrument when placed on a stable pad. The elevation is relative to the gage datum.

Laser Pad Elevation: The elevation of the plane of the laser level pad, upon which the laser level sits.

Levels: Also known as differential leveling, levels are a specific set of procedures conducted with surveying instruments to check that reference marks, reference points, and all gage indexes used to determine gage height are set correctly to the gage datum.

Logging Gage: Typically, an automated bubbler, pressure transducer, or radar gage measures and logs the stage to an electronic data logger, maintaining a continuous record of stage

through a specified period of time. The bubbler or transducer is calibrated to match the primary gage index.

Midsection Method: A widely used technique for calculating stream discharge, the midsection method involves the calculation of discharge in individual measurement cells in a cross-section. The sum of the discharges of each cell comprises the total discharge of the stream.

QRev: Is a Python-based program developed by the United States Geological Survey, Office of Surface Water, to compute ADCP measurements. QRev assists the ADCP operator in post-processing by providing automated quality checks and advanced filtering, as well as estimates of uncertainty that can be used to aid in the quality rating of discharge measurements.

Point of Zero Flow: The elevation of the lowest point of a control structure. Discharge stops when stage reaches the point of zero flow elevation.

Primary Gage Index: The primary gage index (PGI) is the base gage for the station, directly referenced to the stage sensor at the gage. The primary gage index is the most stable and reliable gage at a site. All other gages at a station are considered secondary gage indexes.

Reference Mark: A reference mark is a permanent marker of known elevation above the datum, installed in the ground or on a stable structure in the vicinity of the gauging station.

Reference Point: A reference point is a marker above the zero datum from which gage height can be determined.

Secondary Gage Index: Secondary gage indexes (SGI) are used to confirm the primary gage index. The secondary gage index is used to estimate the value of the primary gage index if the primary gage index is damaged or missing.

Stage: The height of the water surface above a datum.

Streamflow: Discharge of water in a surface stream (river or creek).

Streamflow Records: Compilation of stage data sets, discharge measurements, gage-height observations, rating curves, documentation of observed conditions and actions taken, and all other components used to develop a continuous record of discharge at a gaging station.

Transect: The measurement transect is the course the RiverPro follows across the stream and defines the measurement cross-section. The transect is the basic component comprising a measurement.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Vertical: One of a series of measurement points through the cross-section where depth and velocity are measured.

WinRiver II: WinRiver II is a software program designed to process and store discharge information from the RiverPro. WinRiver II simultaneously processes location information and streamflow data, as well as provides a detailed analysis of measurements performed by the RiverPro.

Acronyms and abbreviations

ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
CFS	Cubic feet per second
CSG	Crest Stage Gage
DCP	Data Collection Platform
DQO	Data Quality Objectives
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EMI	Electromagnetic Interference
EPA	U.S. Environmental Protection Agency
et al.	And others
FMU	Freshwater Monitoring Unit
GOES	Geostationary Operational Environmental Satellite system
GPS	Global Positioning System
HPA	Hydraulic Permit Approval
i.e.	In other words
MQO	Measurement quality objective
NAVD 88	North American Vertical Datum of 1988
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
PGI	Primary Gage Index
PST	Pacific Standard Time
PZF	Point of Zero Flow
QA	Quality assurance
QAMP	Quality Assurance Monitoring Plan

QC	Quality control
RPD	Relative percent difference
SGI	Secondary Gage Index
SOP	Standard operating procedures
TMDL	(see Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area

Units of measurement

°C	degrees centigrade
Cfs	cubic feet per second
Ft	feet
ft/s	feet per second

Quality assurance glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab’s ability to perform analytical methods and produce acceptable data. For Ecology, it is “Formal recognition by (Ecology)...that an environmental laboratory is capable of producing accurate analytical data.” [WAC 173-50-040] (Kammin 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy* (USGS 1998).

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, *Klebsiella* (Kammin 2010).

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time and is characteristic of both the measurement system and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI) (Kammin 2010; Ecology 2004).

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process (USGS 1998).

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured (Ecology 2004).

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS (Kammin 2010; Ecology 2004).

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator (USEPA 1997).

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator (USEPA 1997).

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system (Kammin 2010; Ecology 2004).

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at ± 2 standard deviations from the mean, action limits at ± 3 standard deviations from the mean (Kammin 2010).

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading (Kammin 2010).

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity (USEPA 2006).

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA 2006).

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin 2010).

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment and objective criteria, to determine whether the Measurement Quality Objectives for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability, and integrity, as these criteria relate to the usability of the

data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier – data are usable for intended purposes.
 - J (or a J variant) – data are estimated, may be usable, may be biased high or low.
 - REJ – data are rejected, cannot be used for intended purposes.
- (Kammin 2010; Ecology 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set (Ecology 2004).

Detection limit (limit of detection): The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero (Ecology 2004).

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis (USEPA 1997).

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport (Ecology 2004).

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples (Kammin 2010).

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples (USEPA 1997).

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects (Ecology 2004).

Measurement Quality Objectives (MQOs): Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness (USEPA 2006).

Measurement result: A value obtained by performing the procedure described in a method (Ecology 2004).

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed (EPA 1997).

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples (Ecology, 2004; Kammin 2010).

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero (Federal Register October 26, 1984).

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin 2010).

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all parameters (Kammin 2010; Ecology 2004).

Population: The hypothetical set of all possible observations of the type being investigated (Ecology 2004).

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator (USGS 1998).

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data (Kammin 2010).

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives (Kammin 2010; Ecology 2004).

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data (Ecology 2004).

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[\text{Abs}(a-b)/((a + b)/2)] * 100$$

where “Abs()” is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled (USGS 1998).

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator (USGS 1998).

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population (USGS 1998).

Sample (statistical): A finite part or subset of a statistical population (USEPA 1997).

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit (Ecology 2004).

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method (USEPA 1997).

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method’s recovery efficiency (USEPA 1997).

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin 2010).

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin 2010).

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis (Kammin 2010).

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning (USEPA 2006).

References for QA glossary

- Ecology [Washington State Department of Ecology]. 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. Ecology, Olympia, WA.
<https://apps.ecology.wa.gov/publications/SummaryPages/0403030.html>
- Federal Register. 2025. Appendix B to Part 136, Title 40—Definition and Procedure for the Determination of the Method Detection Limit—Revision 2 [1/5/2025]. Code of Federal Regulations, Federal Register. Washington DC.
<https://www.ecfr.gov/current/title-40/part-136/appendix-Appendix%20B%20to%20Part%20136>
- Kammin, B. 2010. Definition developed or extensively edited by William Kammin 2010. Washington State Department of Ecology, Olympia, WA.
- USEPA [U.S. Environmental Protection Agency]. 1997. Environmental Monitoring and Assessment Program — QA Glossary [Last updated on 2/21/2016].
https://archive.epa.gov/emap/archive-emap/web/html/qa_terms.html
- USEPA [U.S. Environmental Protection Agency]. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4.
<https://www.epa.gov/sites/default/files/2015-06/documents/g4-final.pdf>.
- USGS [U.S. Geological Survey]. 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636.
<https://pubs.usgs.gov/of/1998/ofr98-636/pdf/ofr98636.pdf>.