



January 2026
Study of Physical Data Gaps to Inform the Implementation
of Nur Rematriation Upstream of Shasta Dam
(AB 211 Drought Grant Agreement Number – Q2396040)



Appendix I

Temperature Data Collection Study

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Appendix I: Temperature Data Collection Study

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Attachment 3	Stream Temperature and Discharge Data Collection Standard Operating Procedure
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ABBREVIATIONS

Background Compendium	<i>Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams</i>
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
cfs	cubic foot per second
Consultant Team	Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey; and QEDA Consulting, LLC
Cow Creek Report 2006	<i>Cow Creek Monitoring Project</i>
Cow Creek Report 2001–2003	<i>Cow Creek Water Quality Study 2001–2003</i>
DWR	California Department of Water Resources
HDR	HDR Engineering, Inc.
kg/m ³	kilogram per cubic meter
km	kilometer
m	meter
m/s ²	meter per second squared
PG&E	Pacific Gas and Electric Company
Project	studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area
Nomtipom Waywaket	Winnemem Wintu words for Sacramento River
Nur	Winnemem Wintu word for Chinook Salmon
rkm	river kilometer
RM	river mile
SWAMP	Surface Water Ambient Monitoring Program
TDM	temperature-dependent mortality
TidbiT	HOBO TidbiT MX Temp 400
U20L	HOBO U20L Water Level Logger (i.e., pressure transducer)
USGS	U.S. Geological Survey
Winnemem Waywaket	Winnemem Wintu words for Sacramento River

1 Introduction

1.1 Overview

A team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc. (HDR); U.S. Geological Survey (USGS); and QEDA Consulting, LLC, known herein as the “Consultant Team,” has received funding from the California Department of Fish and Wildlife (CDFW) to implement studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area. These studies are referred to as the “Project.” The results of the Project will support an investigation of the feasibility of providing volitional passage for fish, particularly Chinook Salmon (*Oncorhynchus tshawytscha*) above Keswick and Shasta dams on the Nomtipom Waywaket (also known as the Sacramento River) in northern California. In this document, Chinook Salmon is used to generally describe the species because once connectivity is re-established through reintroduction, fish will adapt to the new environments and could display run timing consistent with multiple runs. It is inclusive of Nur, which the Winnemem Wintu Tribe uses for Chinook Salmon that have been raised by the Tribe. The formal, evolutionarily significant unit-specific name (e.g., Sacramento River winter-run Chinook Salmon) is used when discussing federal Endangered Species Act-listed Chinook Salmon or steelhead. This document is an appendix to the overarching report documenting the results of the Project, which is called the *Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams* (Background Compendium). This larger report contains additional background information for the Project, and this document should be considered within this context.

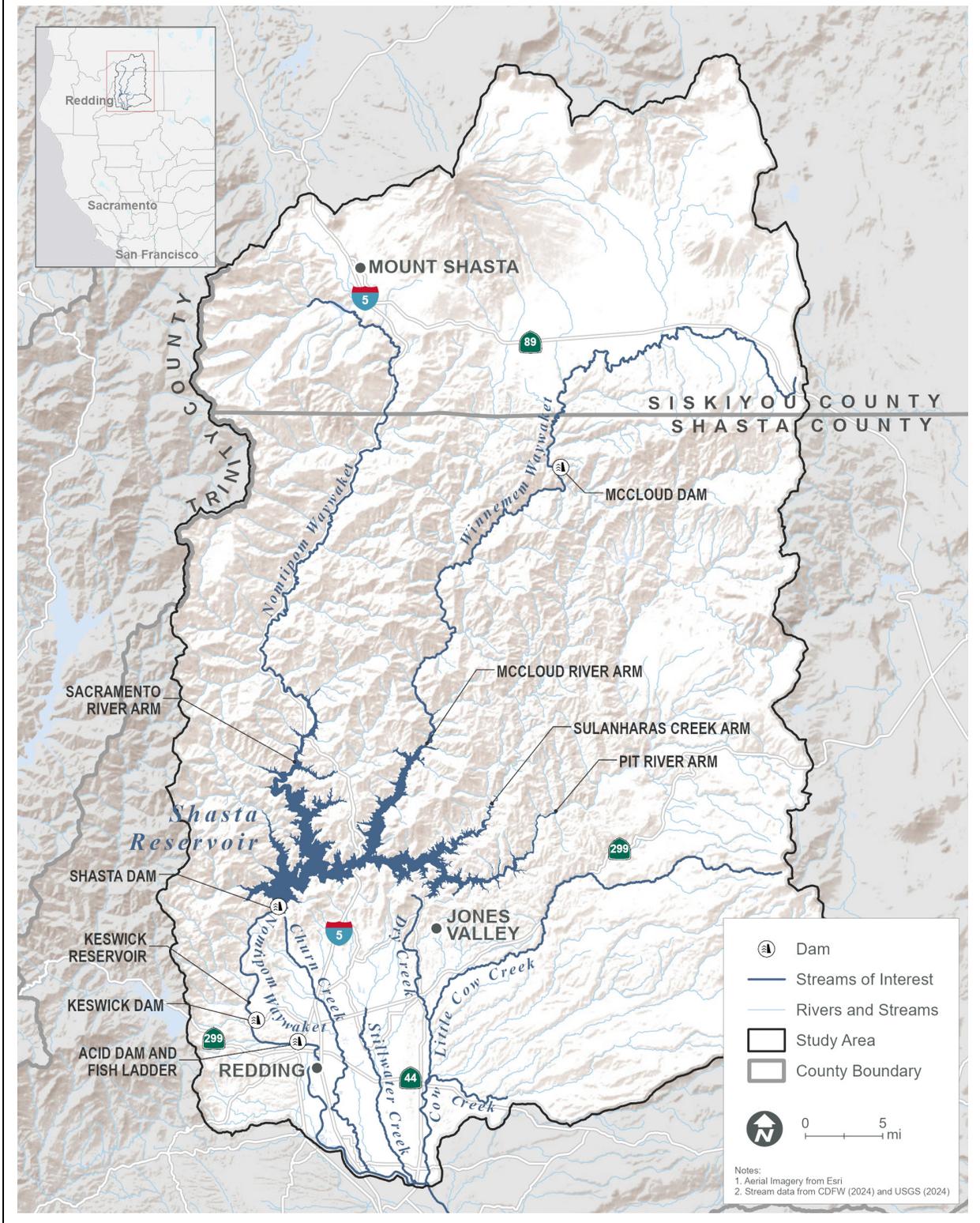
The Project Study Area extends from the confluence of Cow Creek and the Nomtipom Waywaket and includes the Winnemem Waywaket (also known as the McCloud River; in this document, Winnemem Waywaket will be used except when referring to USGS stream gages that use McCloud River in their titles) from Shasta Reservoir to the McCloud Dam (Figure 1). It includes portions of the Winnemem Waywaket; Nomtipom Waywaket, including Keswick and Shasta dams and reservoirs; Dry Creek; Little Cow Creek; and Cow Creek. These water bodies vary in hydrology, geomorphology, and water quality, with seasonal fluctuations in temperature and flow; these parameters are being measured during this Project to evaluate habitat suitability and passage for salmonids. Understanding these physical conditions is essential to evaluating the feasibility of restoring fish passage to historical spawning and rearing areas upstream of the dams.

The purpose of this study is to characterize water temperature along a potential volitional passage migratory pathway. This document summarizes available water temperature data from the Winnemem Waywaket, Shasta Reservoir, Dry Creek, Little Cow Creek, and Cow Creek and describes the methods, results, and discussion for collecting new temperature data in the reservoir and along the same creeks. Although not the primary objective, flow data were collected opportunistically in

Dry Creek, Little Cow Creek, and Cow Creek where limited data were available. Information collected and compiled during the Project will be used to support the volitional passage feasibility study that will be reviewed by the salmon co-managers (Winnemem Wintu Tribe, CDFW, and National Marine Fisheries Service) and used to inform fish passage decisions.

The Winnemem Wintu Tribe shared with the Consultant Team that they do not support the temperature studies as their Indigenous Traditional Ecological Knowledge does not rely on temperature thresholds. Readers should also understand that on December 12, 2025, the Consultant Team received an email stating that the Winnemem Wintu Tribe does not endorse these reports (referring to the Background Compendium and appendices and *Alternatives Formulation and Evaluation Report* [Anchor QEA and HDR 2026]).

Figure 1
Study Area, Key Features, and Project Vicinity



2 Existing Data and Data Gaps

2.1 Summary of Existing Data

Research was conducted to assemble existing water temperature and flow data from the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek. Data were acquired from the following sources:

- California Data Exchange Center (CDEC; 2024)
- USGS (2024)
- California Department of Water Resources (DWR; 2024)
- Surface Water Ambient Monitoring Program (SWAMP; State Water Board 2024)
- *Cow Creek Monitoring Project* (Hannaford and WSRCD 2006)
- *Cow Creek Water Quality Study 2001–2003* (CV Water Board 2003)
- Pacific Gas and Electric Company (PG&E) Technical Memorandum 28 (Stillwater Sciences 2008)
- PG&E Technical Memorandum 66 (Stillwater Sciences 2009)
- CDFW (2024)

Data at each location were assigned to one of three data quality categories: high, medium, and low. The high-quality data are long-term datasets that are collected continuously and include data collection activities that remain currently active. Medium-quality data were collected continuously but do not include current data collection activities. Low-quality data were collected as single point (i.e., discrete) measurements. A summary of the existing data locations, frequency of collection, period of record, and data quality is provided in Table 1. All existing temperature data are provided in Attachment 1.

Existing water temperature and flow data were compiled from the Winnemem Waywaket (Figure 2), Dry Creek, Little Cow Creek, and Cow Creek (Figure 3) from the USGS (2024). A summary of the existing full-flow gages and period of record are provided in Table 2.

Figure 2
Existing Data Locations in the Winnemem Waywaket

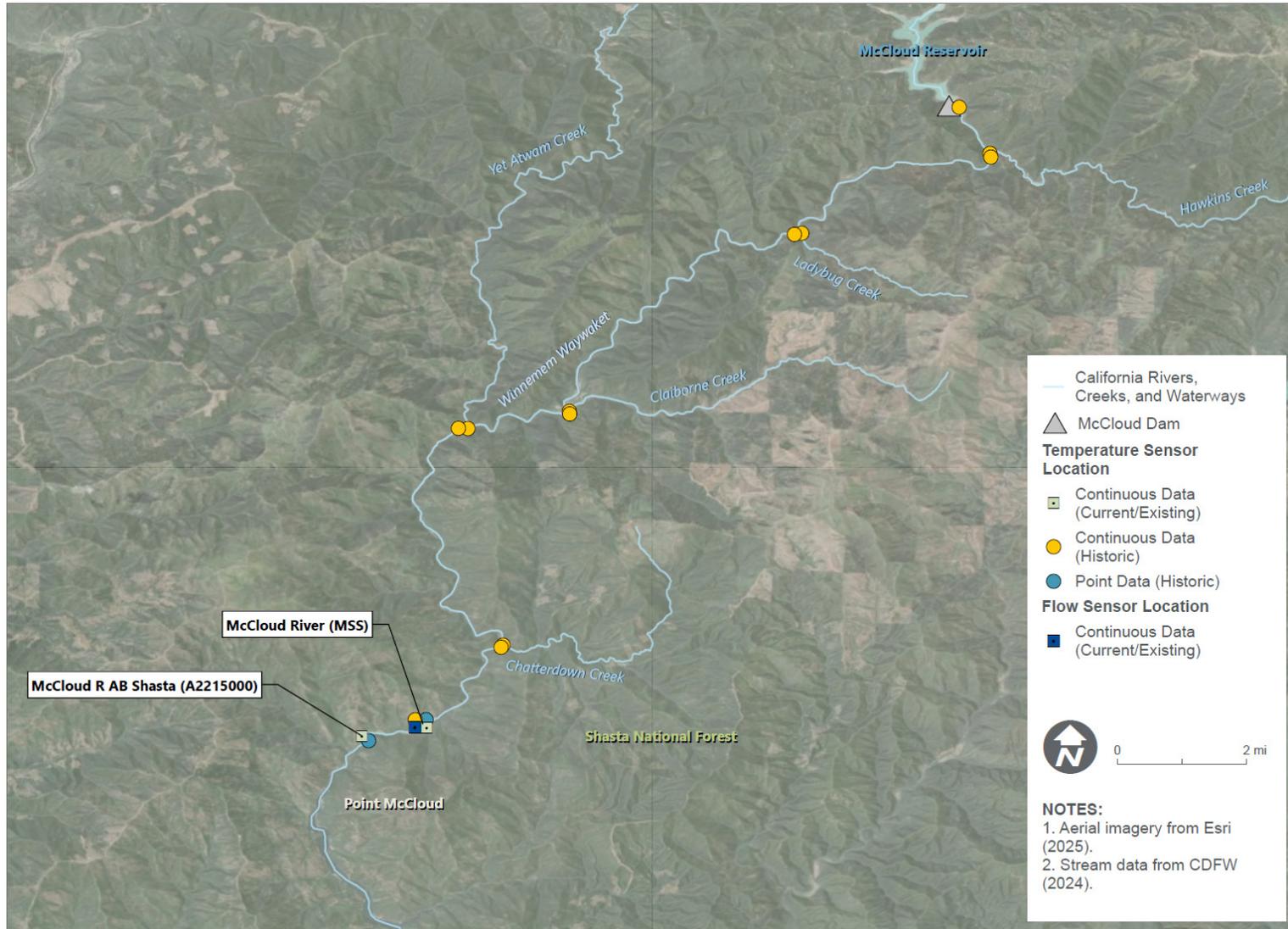


Figure 3
Existing Data Locations in Dry Creek, Little Cow Creek, and Cow Creek

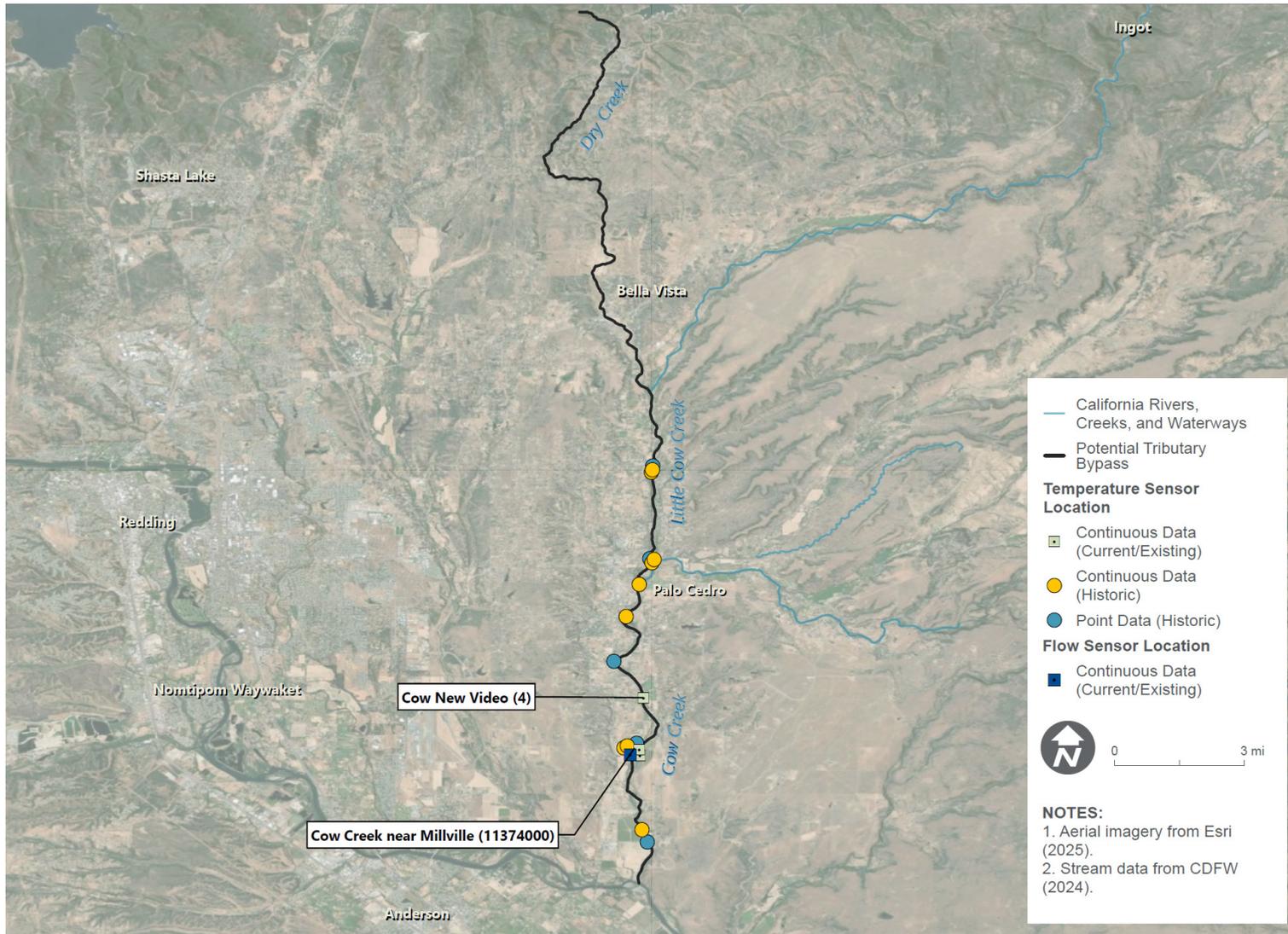


Table 1
Summary of Existing Water Temperature Data

Water Body	Station Name	Station ID (Agency)	RM	Frequency of Collection	Period of Record	Data Quality	
Winnemem Waywaket	Winnemem Waywaket below McCloud Dam	MRB (PG&E) ¹	WW 38.1	Daily	05/04/2007 to 10/31/2007 and 05/02/2008 to 10/31/2008	Medium	
	Winnemem Waywaket above Hawkins Creek	MR1 (PG&E)	WW 36.9	Daily	05/04/2007 to 10/31/2007 and 05/01/2008 to 10/31/2008	Medium	
	Winnemem Waywaket below Hawkins Creek	MR2 (PG&E)	WW 36.9	Daily	05/04/2007 to 10/31/2007 and 05/01/2008 to 10/31/2008	Medium	
	Winnemem Waywaket above Ladybug Creek	MR3A (PG&E)	WW 32.9	Daily	06/29/2007 to 10/31/2007 and 05/02/2008 to 10/31/2008	Medium	
	Winnemem Waywaket below Ladybug Creek	MR3B (PG&E)	WW 32.8	Daily	05/22/2007 to 10/31/2007 and 05/02/2008 to 10/31/2008	Medium	
	Winnemem Waywaket above Claiborne Creek	MR4A (PG&E)	WW 26.2	Daily	05/02/2007 to 10/31/2007 and 05/03/2008 to 10/31/2008	Medium	
	Winnemem Waywaket below Claiborne Creek	MR4B (PG&E)	WW 26.2	Daily	05/02/2007 to 10/31/2007 and 05/03/2008 to 10/31/2008	Medium	
	Winnemem Waywaket above Yet Atwam Creek	MR5A (PG&E)	WW 24.2	Daily	06/21/2007 to 10/31/2007 and 05/03/2008 to 10/31/2008	Medium	
	Winnemem Waywaket below Yet Atwam Creek	MR5B (PG&E)	WW 24.1	Daily	05/02/2007 to 10/31/2007 and 05/03/2008 to 10/31/2008	Medium	
	Winnemem Waywaket above Chatterdown Creek	MR6A (PG&E)	WW 18.5	Daily	06/22/2007 to 10/31/2007 and 06/06/2008 to 10/31/2008	Medium	
	Winnemem Waywaket below Chatterdown Creek	MR6B (PG&E)	WW 18.5	Daily	06/22/2007 to 10/31/2007 and 06/06/2008 to 10/31/2008	Medium	
	McCloud R AB Shasta LK CA		11368000 (USGS) and MR7 (PG&E) ²	WW 16.2	Monthly	10/09/1967 to 09/02/1980	Medium
					Daily	06/22/2007 to 10/31/2007 and 05/01/2007 to 10/31/2008	
Winnemem Waywaket	MSS (CDEC)	WW 16.1	Hourly	11/18/1989 to present	High		

Water Body	Station Name	Station ID (Agency)	RM	Frequency of Collection	Period of Record	Data Quality
Winnemem Waywaket (cont.)	McCloud R AB Shasta	A2215000 (DWR)	WW 15.2	Daily	05/13/2008 to 05/09/2023	High
	Winnemem Waywaket above Shasta Lake	506SHA953 (SWAMP)	WW 15.2	Quarterly	02/23/2009 to 05/12/2020	Low
Shasta Reservoir	No Data Obtained					NA
Dry Creek	No Data Available					NA
Little Cow Creek	Lower Little Cow Creek at Swede Creek Rd	503 (Cow Creek Report 2006) ²	CC 10.1	Daily	05/2004 to 10/2005	Medium
	Cow C L A Swede C Rd	A4835200 (DWR)	CC 10.1	Point collections	09/14/1977 to 01/12/1979	Low
	L Cow Temp Gauge	No ID listed (CDFW)	CC 10.1	Daily	08/28/2020 to 12/03/2021	Medium
	Lower North Cow	LNC (Cow Creek Report 2001–2003) ³	CC 8.1	Daily	04/2001 to 09/2001, 04/2002 to 09/2002, and 06/21/2003 to 11/26/200	Medium
	Cow C L A Palo Cedro	A4835000 (DWR)	CC 8.1	Point collections	03/29/1955 to 12/23/1982	Low
Cow Creek	Cow Creek Mainstem	Main (Cow Creek Report 2001–2003) ²	CC 8.0	Daily	04/2001 to 09/2001 and 04/2002 to 09/2002	Medium
	Old Cow/Little Cow Confluence at Hwy 44	201 (Cow Creek Report 2006) ²	CC 7.5	Daily	05/2004 to 10/2005	Medium
	Mainstem Cow Creek	002 (Cow Creek Report 2006) ²	CC 6.7	Daily	05/2004 to 10/2005	Medium
	Cow C NR Palo Cedro	A4811100 (DWR)	CC 5.4	Point collections	09/23/1974 to 08/05/2008	Low
	Cow New Video	4 (CDFW)	CC 4.4	Hourly	09/05/2017 to present	High
	Cow Creek near Millville	A4811000 (DWR)	CC 3.1	Point collections	02/03/1955 to 11/07/2023	High
				Daily	11/21/2008 to 11/07/2023	High
	Cow C NR Millville	11374000 (USGS)	CC 3.1	Daily	07/13/1977 to 06/01/1978	Medium
	Cow Creek at Dream Catcher Ln	508SHA905 (SWAMP)	CC 3.1	Quarterly	02/23/2009 to 05/12/2020	Low
Mainstem Cow Creek at USGS Gauge	001 (Cow Creek Report 2006) ²	CC 3.1	Daily	05/2004 to 10/2005	Medium	

Water Body	Station Name	Station ID (Agency)	RM	Frequency of Collection	Period of Record	Data Quality
	Cow Mouth or Old Video	3 (CDFW)	CC 1.2	Hourly	09/07/2006 to 11/1/2017	Medium
	Cow C NR Anderson	A4810100 (DWR)	CC 0.9	Point collections	11/30/1960 to 03/03/1983	Low

Notes:

1. MRB station is missing data from 07/03/2008 to 08/06/2008.
2. Did not obtain data for this location from the noted report
3. Only obtained data for 06/21/2003 to 11/26/2003

Table 2
Summary of Existing Flow Data

Water Body	Station Name	USGS Gage ID	Period of Record
Winnemem Waywaket	At Ah-Di-Na near McCloud	11367800	10/01/1964 to 09/30/2023
	Above Shasta Lake	11368000	10/01/1945 to 09/30/2023
Cow Creek	Near Millville	11374000	10/01/1949 to present

2.2 Identification of Data Gaps

Aside from two continuous water temperature monitors on the Winnemem Waywaket and one on Cow Creek, available water temperature data are sparse along the reaches of interest. Due to the length of these water bodies, there is limited resolution in determining the seasonal variability in water temperature, temperature gains and/or losses along the reaches of interest, and the temperature impacts from major tributary inflows. A discussion of existing high-quality and medium-quality water temperature data and remaining water temperature data gaps are presented by reach in Sections 2.2.1 through 2.2.4.

Continuous flow gages are available on both the Winnemem Waywaket and Cow Creek. On the Winnemem Waywaket, a full-flow gage exists upstream of Shasta Lake and slightly downstream of Lake McCloud. Contributing inflow from the Winnemem Waywaket reach of interest was calculated as the difference in flow between these two gages. Gage area proration can be used to estimate inflow from specific runoff areas, like major tributaries, if needed. No additional flow information is needed for the Winnemem Waywaket given these two existing gages. No flow data are available on Dry Creek or Little Cow Creek, so pressure transducers with temperature sensors were installed at one location on both Dry Creek and Little Cow Creek, as well as just upstream of the confluences of Little Cow with Cow Creek and Dry Creek with Little Cow Creek, to assess thermal inputs and interactions at these junctions.

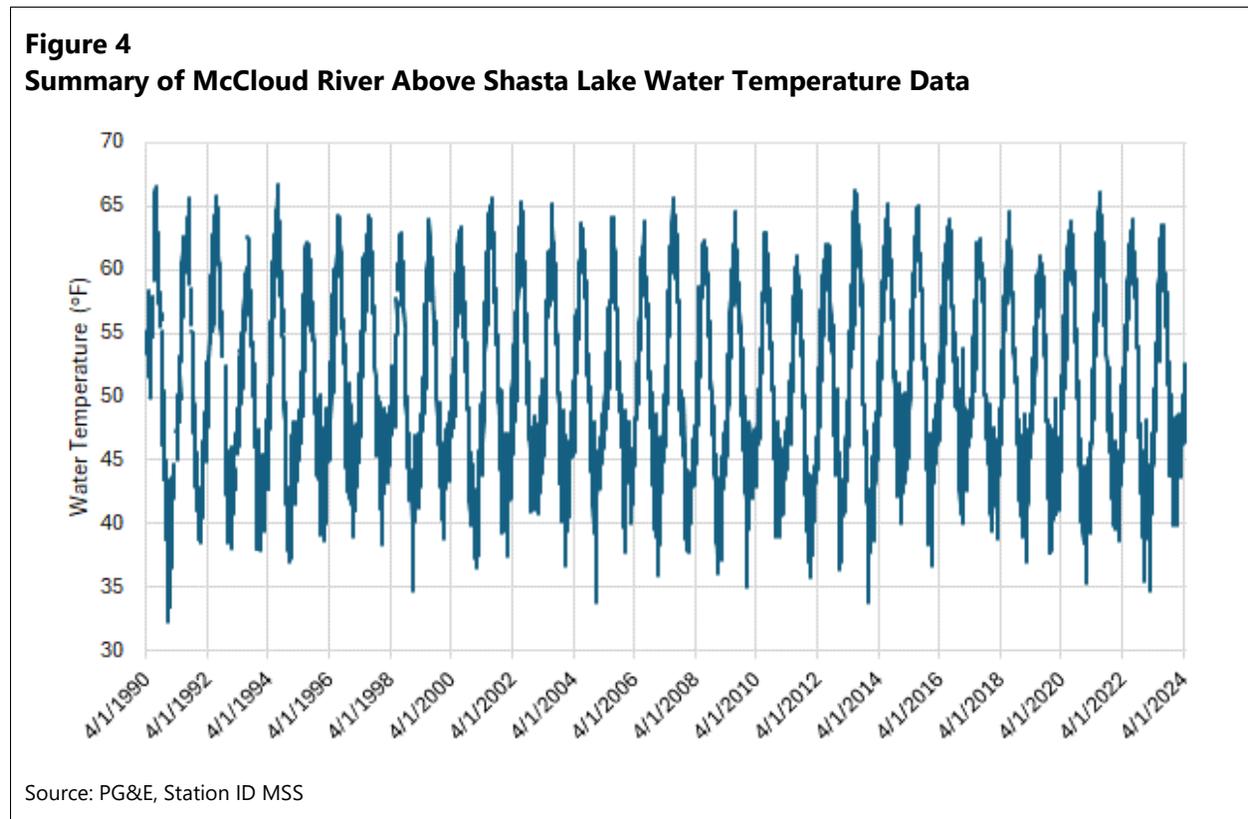
It was observed during the field visit on June 3, 2024, that the Cow Creek gage was potentially overestimating flow at low stages. Low-flow calibration of this gage last occurred in water years 2020 and 2021. To address concerns regarding the accuracy of the existing gage, a new pressure transducer with a temperature sensor was installed adjacent to the gage, allowing for additional flow data to be collected to verify gage readings or, if necessary, to develop a correction factor to estimate low flows using existing gage height data.

The following sections summarize existing data and data quality for various areas of the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek and identify locations where additional data are needed. Specific locations for new data collection sites are described in Section 3.1. See Section 3

for the details of deployment of temperature sensors and pressure transducers and Section 4 for the analysis of all temperature data.

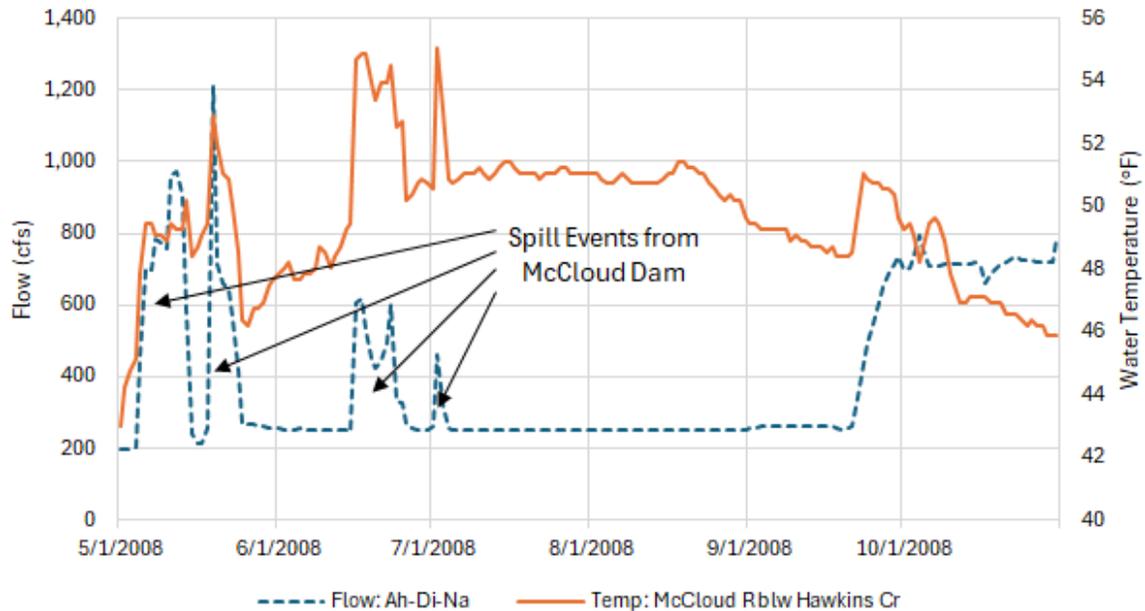
2.2.1 Winnemem Waywaket

As summarized in Section 2.1, a high-quality water temperature gage exists for the Winnemem Waywaket above Shasta Lake (PG&E Station ID MSS), characterized as a long-term dataset, collected on a continuous basis, and still active. See Figure 4 for summary of temperature data dating back to 1990.



PG&E also collected water temperature data along the Winnemem Waywaket at seven locations between McCloud Dam and Shasta Reservoir between May 1, 2007, and October 31, 2007, and between May 1, 2008, and October 31, 2008. The USGS flow gage at Ah-Di-Na (USGS 11367800) indicates periods of spill from McCloud Dam in May, late June, and early July of 2008 corresponding to spikes in observed water temperature. There was no spill from McCloud Dam observed in 2007. Figure 5 presents water temperature at a single location in the Winnemem Waywaket along with flow at the USGS gage at Ah-Di-Na in 2008, demonstrating the relationship between temperature and flow.

Figure 5
Summary of McCloud River Flow and Water Temperature Data in 2008, Highlighting Period of Spill from McCloud Dam



Based on data measured in 2007 and 2008, temperature consistently increased from upstream (below McCloud Dam) to downstream (above Shasta Reservoir) from May through October when McCloud Dam is not spilling (Figures 6 and 7). Water temperature of incoming tributaries was always warmer than flows in the Winnemem Waywaket, contributing to warming along the reach. The largest tributary along this reach of the Winnemem Waywaket is Yet Atwam Creek. Other tributaries along this reach are Chatterdown Creek and Claiborne Creek.

Figures 6 and 7 show the approximate location of the two temperature tolerance limits, 53.5°F¹ and 56°F,² for 2007 and 2008, respectively (note spill periods from McCloud Dam were removed from Figure 7). These tolerance limits were selected to cover the uncertainty and variability associated with temperature-related egg mortality. The vertical axis in these figures represents river miles (RMs) upstream of Shasta Dam.

¹ Optimal egg incubation temperature range for Chinook Salmon is between 42.8°F and 53.5°F (Myrick and Cech 2004).

² Water Right Order 90-5 originally required a daily average temperature of $\leq 13.3^{\circ}\text{C}$ (56°F) in the Nomtipom Waywaket from Keswick Dam (river kilometer [rkm] 486, RM 302) to RBDD (rkm 389, RM 242) during the temperature management season from May 15 through October 31 (SWRCB 1990) to facilitate winter-run Chinook Salmon egg incubation.

Figure 6
Summary of Winnemem Waywaket Temperature Data, 2007

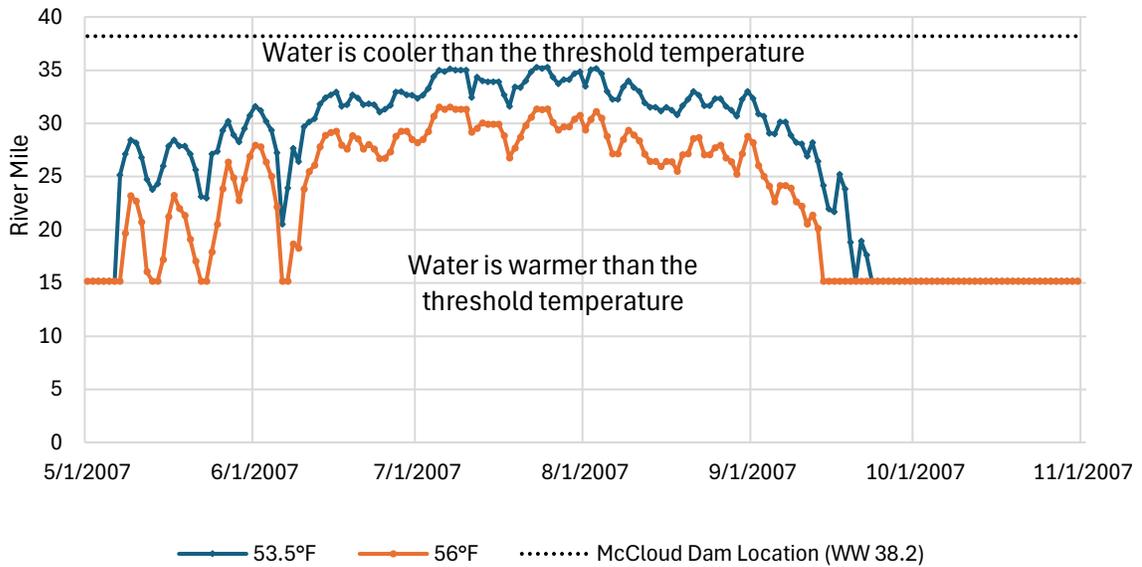
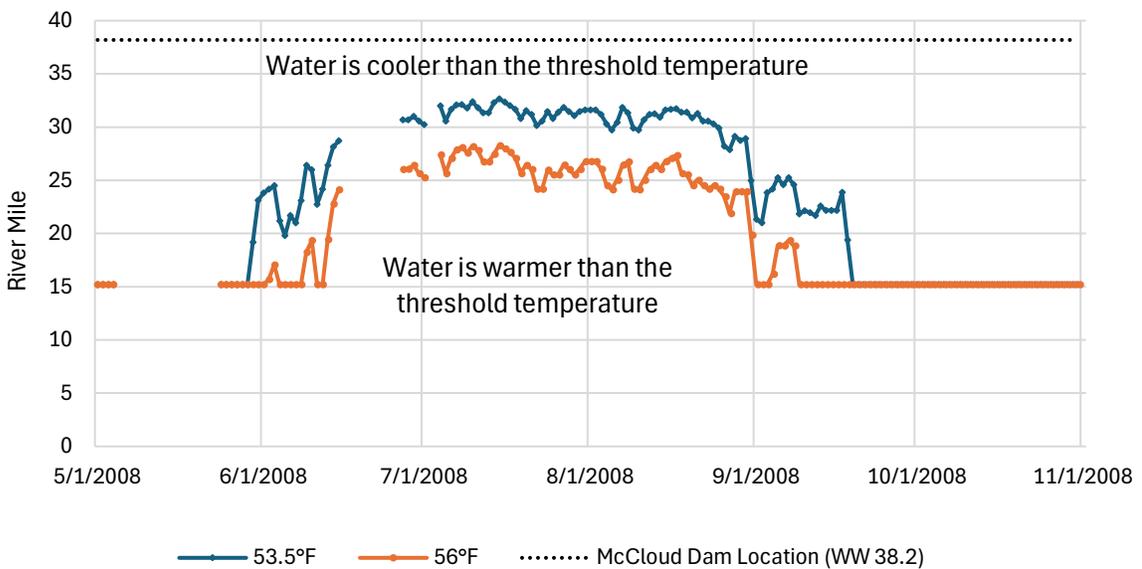


Figure 7
Summary of Winnemem Waywaket Temperature Data, 2008



Based on available data from 2007 and 2008, the location of the 53.5°F maximum optimal temperature for egg incubation in the Winnemem Waywaket in July and August ranged from approximately RM 28.9 and RM 35.9, which is in the vicinity of the Ladybug Creek confluence (RM 32.9) and the confluence of Claiborne Creek (RM 26.2); the location of the 56°F Water Right Order 90-5 (State Water Board 1990) daily average egg incubation tolerance limit in the Winnemem Waywaket ranged from approximately RM 24 and RM 31, which is in the vicinity of the Claiborne Creek confluence (RM 26.2) and the Yet Atwam Creek confluence (RM 24.2). To obtain more current data and to better understand the influence of Ladybug Creek and Claiborne Creek on Winnemem Waywaket water temperature, temperature sensors were placed in the Winnemem Waywaket at the following locations:

- Immediately upstream of Ladybug Creek
- Immediately downstream of Ladybug Creek
- Immediately upstream of Claiborne Creek
- Immediately downstream of Claiborne Creek
- Immediately upstream of Yet Atwam Creek

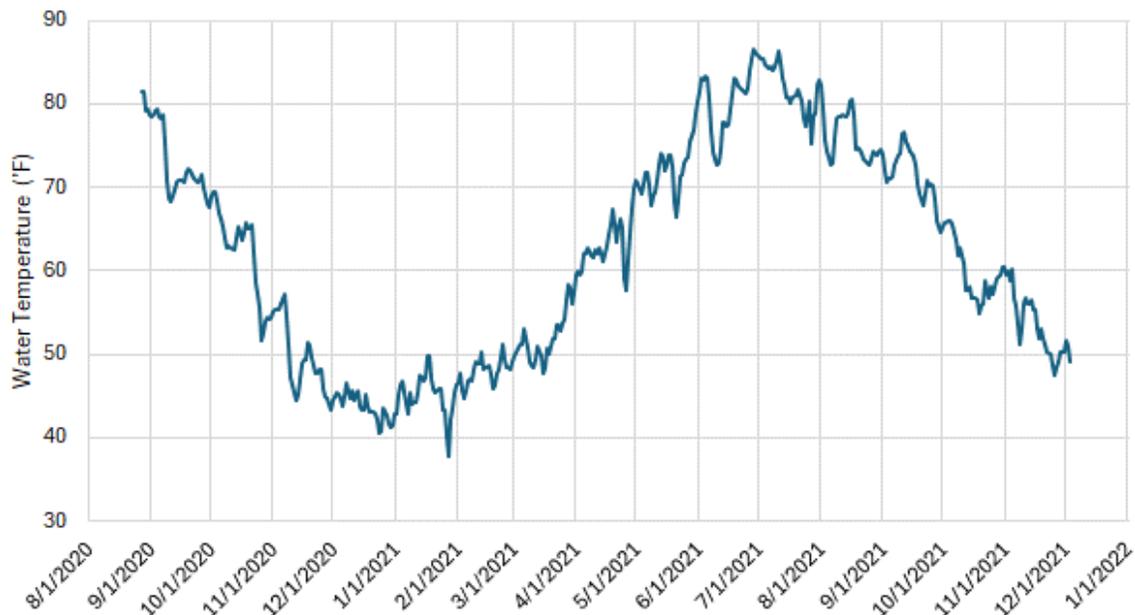
2.2.2 Dry Creek

No water temperature data have been collected previously in Dry Creek. As such, there is a data gap related to water temperature in Dry Creek upstream of the Dry Creek and Little Cow Creek confluence. To address this data gap, one temperature sensor was placed in Dry Creek upstream of the confluence, and one temperature sensor was placed in Little Cow Creek upstream of the confluence. The sensor in Dry Creek was also a pressure transducer, which provided water level data.

2.2.3 Little Cow Creek

There was previously a water temperature gage in Little Cow Creek at Swede Creek Road approximately 2.6 miles upstream of the Little Cow Creek and Cow Creek confluence (Figure 8). The data from this gage were classified as medium quality since its period of record is relatively short.

Figure 8
Data Summary for Little Cow Creek at Swede Creek Road

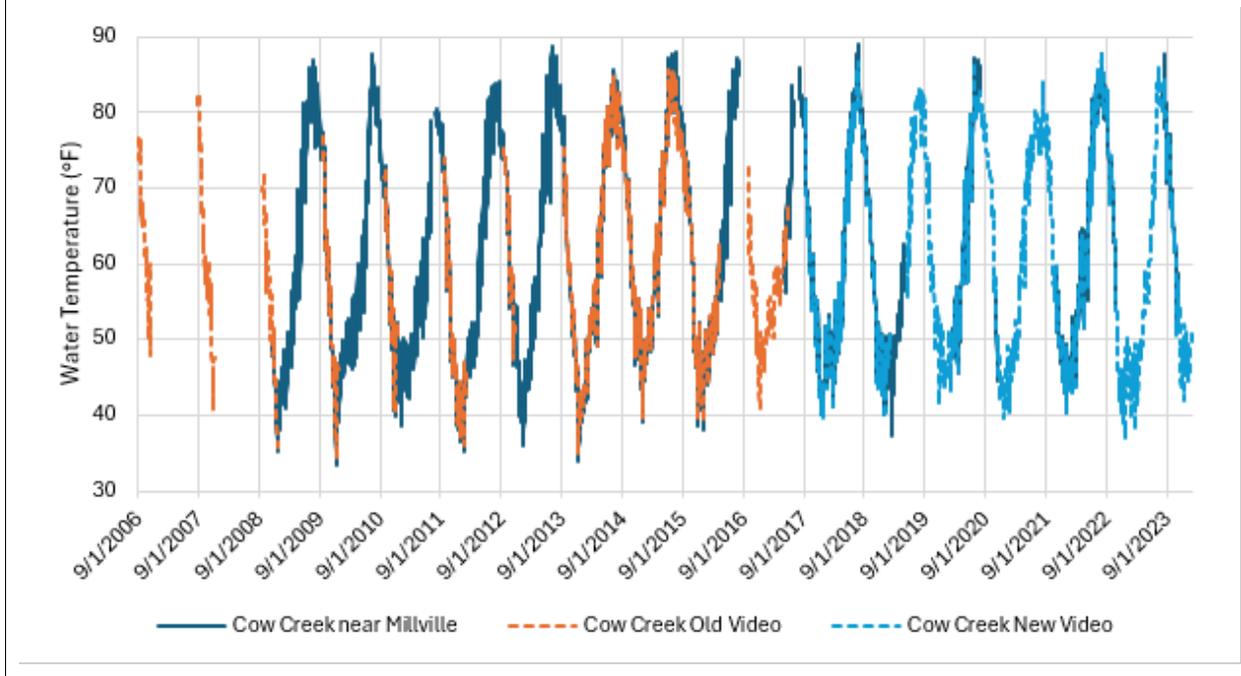


To characterize the difference in temperature near the Little Cow Creek and Cow Creek confluence, one temperature sensor was placed in Little Cow Creek upstream of the Cow Creek confluence, and one temperature sensor was placed in Cow Creek upstream of the Little Cow Creek confluence. Additionally, the sensor in Little Cow Creek was also a pressure transducer, which provided water level data.

2.2.4 Cow Creek

Between the Cow Creek Old Video sensor, Cow Creek New Video sensor, and Cow Creek near Millville gage records, there are high-quality data and characterization of historical temperature in Cow Creek between the Little Cow Creek confluence and Nontipom Waywaket (Figure 9). This period of record ends on January 29, 2024. To ensure continuity of data collection, a sensor was deployed near the existing sensor locations in the event that data from the gage were not available during the monitoring period (i.e., September 2024 through August 2025). There are no major tributary inflows downstream of these gages to the confluence with the Nontipom Waywaket.

Figure 9
Historical Temperature in Cow Creek Upstream of the Nomtipom Waywaket



2.2.5 Summary

The locations identified above in Dry Creek, Little Cow Creek, and Cow Creek are the most important locations to collect water temperature data for characterization of flow and water temperature conditions along the migratory pathway. Additional temperature data at intermediate reach locations would be helpful but, given the difficulties surrounding access, are not deemed necessary. Existing temperature data from the Shasta Reservoir were not included in this study because it was an opportunistic addition to the Project.

3 Methods

To fill the data gaps identified in Section 2.2, instream water temperature sensors and pressure transducers were placed to collect data over approximately 1 year. Data from the pressure transducers were used to determine depth for the flow calculations. These data were used to characterize flow and water temperature along the potential migratory pathway and to evaluate thermal suitability and water availability to support the alternatives evaluation as part of the Volitional Fish Passage Alternatives Development and Evaluation Study.

3.1 Locations

Water temperature sensors and pressure transducers were deployed in numerous locations on the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek. Table 3 provides the river mileage for each water body within the Study Area. Additionally, a temperature profile string was opportunistically deployed on the Shasta Reservoir approximately 1.6 kilometer (km) northeast of Jones Valley Public Boat Launch to document temperature at multiple depths, including the surface, 1 meter (m), 3 m, 10 m, 20 m, 40 m, and 60 m.

Table 3
Summary of River Mileage

Water Body	RM
Winnemem Waywaket	24.16
Dry Creek	9.14
Little Cow Creek	4.40
Cow Creek	7.45

Figures 10 and 11 show the temperature sensor and pressure transducer installation sites, which were determined based on data gaps discussed in Section 2.2 and site accessibility. Both figures include an inset that shows the locations of all install sites, including the temperature string in Shasta Reservoir.

Figure 10
Temperature Sensor Installation Sites on the Winnemem Waywaket

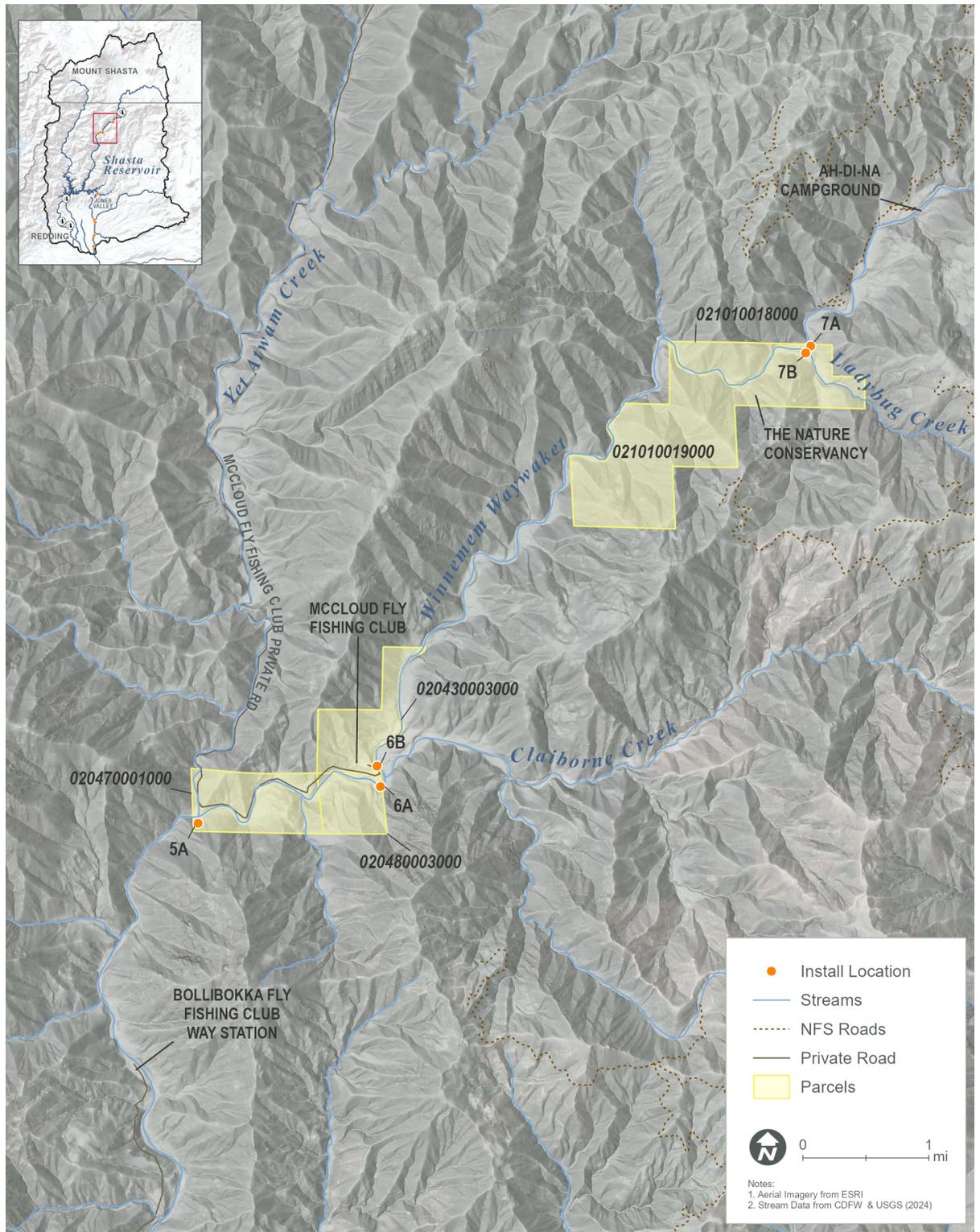
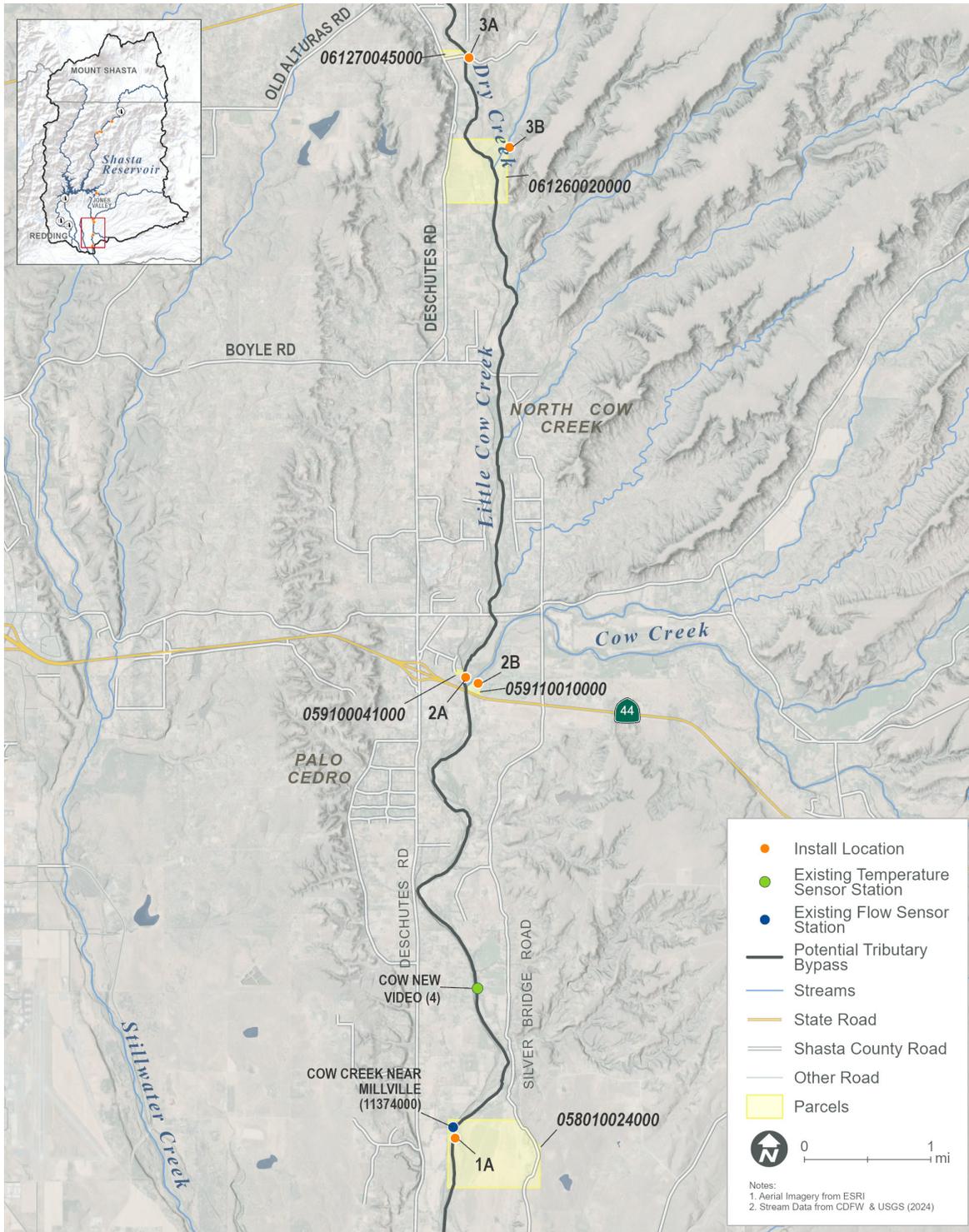


Figure 11
Temperature and Water Level Sensor Installation Sites on Dry Creek, Little Cow Creek, and Cow Creek



3.1.1 *Location Requirements*

For the Winnemem Waywaket, proposed locations were identified based on road access and proximity to locations coincident with temperature tolerance limits listed in Section 2.2.1 based on existing temperature data. These locations are important to identify any temperature-related limiting factors to salmon habitat for egg incubation in Winnemem Waywaket. The locations were also selected to provide information on the influence of key tributaries (Ladybug Creek, Claiborne Creek, and Yet Atwam Creek) on the temperature profile of the Winnemem Waywaket. Temperature sensors were installed at the following locations:

- Immediately upstream of Ladybug Creek
- Immediately downstream of Ladybug Creek
- Immediately upstream of Claiborne Creek
- Immediately downstream of Claiborne Creek
- Immediately upstream of Yet Atwam Creek

For Dry Creek, Little Cow Creek, and Cow Creek, proposed locations were identified based on proximity to each confluence (e.g., Dry Creek and Little Cow Creek confluence) to address the data gaps identified in Section 2.2, and the channel configuration (straight channel, no obvious pools immediately upstream or downstream, no obvious constriction points, and apparent suitable substrate or bank conditions for securing the sensor). Temperature sensors and pressure transducers were installed at the locations listed below to assess thermal inputs and interactions at these junctions.

- Dry Creek
 - In Dry Creek upstream of the confluence with Little Cow Creek
 - In Little Cow Creek upstream of the confluence with Dry Creek
- Little Cow Creek
 - In Little Cow Creek upstream of the Cow Creek confluence
 - In Cow Creek upstream of the Little Cow Creek confluence
- Cow Creek
 - Near existing USGS Millville gage

Actual sensor locations were ultimately determined by landowner permissions granted from the process outlined in Section 3.1.3.

3.1.2 *Access*

Based on the data gaps described in Section 2.2, property parcels were identified that achieved the location requirements described in Section 3.1.1 and accounted for road access and topographical limitations. A total of 34 parcels were identified, and HDR contacted the tax assessor's office to obtain landowner and mailing address information. A property access request letter was drafted and

mailed out to each of the identified landowners. The request letter provided a summary of the study objectives, a brief description of the data collection methods, and a formal request to obtain permission for the field team to access their property. When available, landowners were also contacted by phone and/or email to provide another avenue for outreach. In total, 15 landowners granted access to their parcels, including the top prioritized sites. No letters were returned denying access. All selected parcels had landowners that required prior notice before the field crews accessed their properties. Final sites were chosen based on access restraints, landowner permission, and proximity to river confluences. Based on the access provided and a site survey performed during the summer of 2024, the installation locations and associated parcels selected are listed in Table 4 and corresponding maps are presented in Figures 10 and 11. Detailed site maps with field images are presented in Attachment 2.

Table 4
Summary of Sensor Installations

Location ID	Parcel No.	Number and Type of Sensors ^{1,2}	Description of Location	Latitude (dd.dd)	Longitude (dd.dd)
7A	21010019000	3, TidbiT	Downstream of Ladybug Creek	41.0945	-122.1136
7B	21010018000	3, TidbiT	Upstream of Ladybug Creek	41.0937	-122.1143
6B	20430003000	3, TidbiT	Upstream of Claiborne Creek	41.0460	-122.1794
6A	20480003000	3, TidbiT	Downstream of Claiborne Creek	41.0437	-122.1789
5A	20470001000	3, TidbiT	Just downstream of Yet Atwam Creek	41.0394	-122.2066
4A	NA	7, TidbiT	Approximately 1.6 km northeast of Jones Valley Public Boat Launch	40.7526	-122.2082
3B	61260020000	1, U20L	Little Cow Creek just upstream of the divergence with Dry Creek	40.6177	-122.2252
3A	61270045000	3, U20L (2 in stream, 1 barometric in tree)	Meyer Road bridge at Dry Creek	40.6280	-122.2313
2B	59150010000	2, U20L	Golf course just north of Highway 44 accessed from Highway 44	40.5561	-122.2297
2A	59100041000	2, U20L	Little Cow Creek just north of Highway 44 off Chaps Lane	40.5568	-122.2316
1A	58010024000	2, U20L	Cow Creek USGS Gage location	40.5038	-122.2330

Notes:

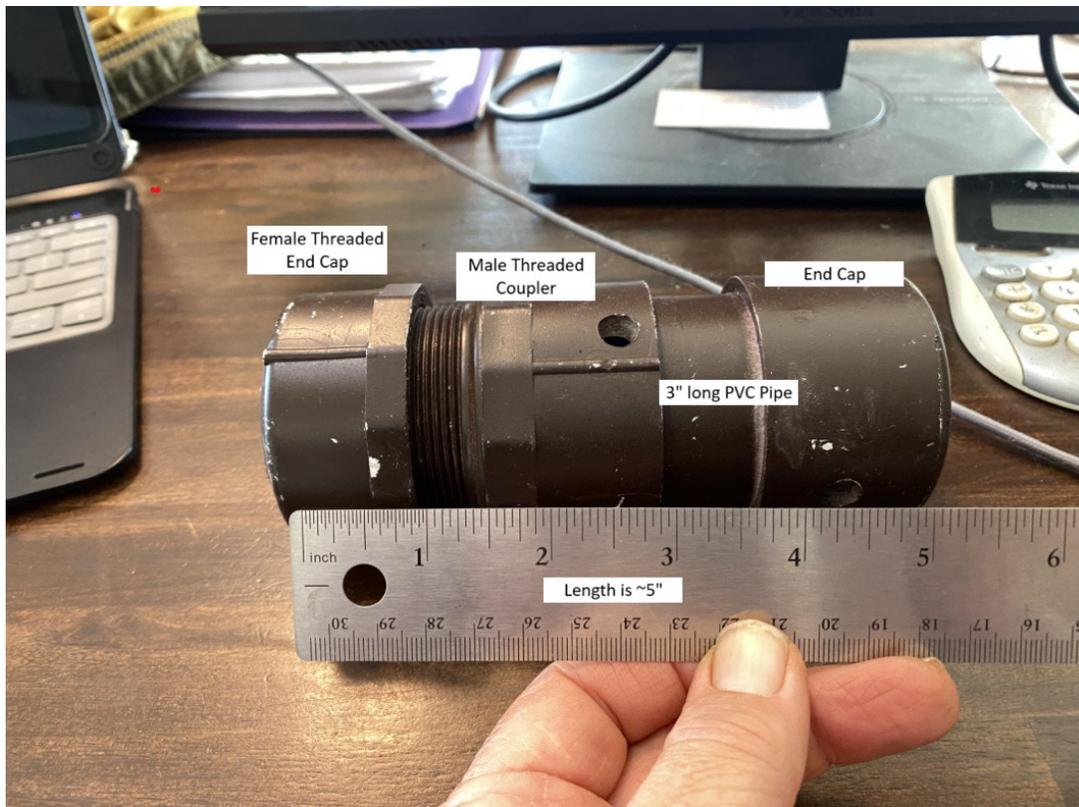
1. U20L is a pressure transducer that measures temperature and pressure. The pressure measurement was used to calculate water depth using the barometric reading at Location 3A.
2. TidbiT measures temperature only.

3.2 Data Collection

Stream data were collected over approximately a 1-year period starting in September 2024. The data were collected with two different data sensors: HOBO TidbiT MX Temp 400 (TidbiT) and HOBO U20L Water Level Logger (U20L, also referred to as a “pressure transducer” in this document). The TidbiT sensors were installed in the Winnemem Waywaket and were also used in June 2025 to replace several U20L sensors lost over the duration of the study. The U20L sensors were installed in Dry Creek, Little Cow Creek, and Cow Creek.

The TidbiT sensors were deployed at five locations in the Winnemem Waywaket, identified in Section 3.1.2. The sensors used Bluetooth Low Energy for wireless communication with a phone, tablet, or computer. A protective housing was built for the TidbiT sensors using approximately 3 inches of PVC pipe, capped on both ends, with holes drilled that allowed for river water to pass through (Figure 12). An end cap and threaded coupler were glued onto either side of the housing, with a female threaded end cap that allows for access into the housing. The housing was approximately 5 inches in total length and was painted brown to blend in with the surrounding environment.

Figure 12
HOBO TidbiT Protective Housing



U20L sensors were installed at each of the five locations identified in Section 3.1.3 in Dry Creek, Little Cow Creek, and Cow Creek. In addition to recording stream temperature, the U20L sensor records absolute pressure, which was later converted to water level readings by HOBOWare Pro software. In this application, absolute pressure included atmospheric pressure and water head. Atmospheric pressure is nominally 100 kilopascals (14.5 pounds per square inch) at sea level, but it changes with weather and altitude. Left uncompensated, barometric variations could result in errors of 0.6 m (2 feet) or more. To compensate for barometric pressure changes, an additional U20L was installed at Location 3A as a barometric reference. Rather than being placed in the water column, the barometric reference was deployed above the water in the air. Water depth was then calculated as follows:

Equation 1

$$\frac{(\text{absolute pressure} - \text{barometric pressure})}{(\rho \times g)} = \text{depth}$$

where:

ρ = water density (1,000 kg/m³)

g = gravitation acceleration (approximately 9.80665 m/s²)

Prior to sensor installation, Anchor QEA confirmed with CDFW that the sensor installations did not meet the criteria for requiring a Lake and Streambed Alteration Permit (CDFW 2024; CDFW and USFWS 2024). Before the sensors were deployed, the TidbiT sensor and U20L sensor software packages were installed on a PC or smartphone, and the sensors were configured. The installation and download activities for each sensor are outlined in a Standard Operating Procedure included as Attachment 3.

Data management activities will be coordinated by Anchor QEA and will adhere to peer -approved methods, undergoing quality control and accuracy assessments while meeting CDFW's minimum metadata standards. All data collected included associated metadata documenting collection details, methods, purposes, and any related permits or agreements. Geospatial data will be delivered in an industry-standard format, and relevant data will be uploaded to databases, such as CEDEN, as required.

During installation, data download, and removal site visits, real-time water velocity was measured at each location using a Swoffer Model 3000. Attachment 3 also includes details on collecting water velocity measurements.

3.3 Data Analysis

Data used in this analysis will consist of newly collected temperature data from sensors mentioned in Section 3.1. Analysis included calculating summary statistics based on all logged data, such as mean, median, maximum, and minimum water temperature, and comparing these statistics across seasons. Additionally, temperature readings from each data sensor were plotted over time to analyze seasonal and interannual variability as well as to compare to maximum optimal temperatures by life stage established in the *Nomtipom Waywaket (Sacramento River) Chinook Salmon Life History Summary* (Appendix N of the Background Compendium).

3.4 Schedule

The sensors were deployed in early September 2024 and were removed in late August 2025. Data were downloaded intermittently throughout the data collection year. The interim data downloads were planned to occur at a minimum of once per quarter, weather permitting. During each data download event, the field crew inspected and cleaned the sensors as needed. The temperature string in Shasta Reservoir was deployed continuously between September 2024 and May 2025. No data download events occurred during the deployment period.

4 Results

4.1 Deviations

Over the duration of the Project, there were minor deviations from the study work plan due to extenuating circumstances as described in the following:

- In December, the first data download at The Nature Conservancy sites (Locations 7B and 7A) was canceled after snowy road conditions rendered the sites inaccessible.
- The second data download event for all sites planned for April was delayed because the Winnemem Waywaket sites remained affected by residual snow cover and elevated streamflows. These conditions not only limited physical access but also presented safety risks. As a result, timing of the second data download was deferred to May to accommodate safe access while maintaining alignment with overall Project objectives.
- When reviewing the data, it was determined that the temperature at Location 6B starting in mid-January indicated the sensor may have been dislodged and was no longer submerged. This was based on the temperature range on a given day and the extremely cold temperature measured, more consistent with air temperature at that time of year. Therefore, all data from Location 6B were excluded from further analysis after mid-January.
- When the temperature string in Shasta Reservoir was recovered, it was discovered that the deepest sensor at 60 m was inoperable, resulting in no data retrieval for that depth.
- Elevated flows that occurred after the December temperature data download resulted in the loss of multiple temperature sensors across several monitoring locations. Specifically, the sole sensor at Location 3B, both sensors at Locations 2A and 3A, and one of the two sensors at Location 1A, were all dislodged by currents and lost. TidbiT sensors were installed to replace the lost U20L sensors on June 11, 2025.
- During the May download event, it was discovered that the sensors were lost, and velocity measurements could not be taken due to a combination of equipment issues and hazardous river conditions. Instead, velocity measurements were taken on June 11, 2025.

4.2 Findings

The findings from this study are described in the following sections for the Winnemem Waywaket, Shasta Reservoir, Dry Creek, Little Cow Creek, and Cow Creek. Temperature data have been collected over the past 12 months and are presented in the following sections as seasonal summary statistics, including the mean, median, maximum, and minimum temperature, and graphically in seasonal and annual plots. All data were converted into DSS format, which can be viewed using free software from the U.S. Army Corps of Engineers and are provided in Attachment 4. The data collected as part of this study are being used by the Consultant Team for additional studies, including the thermal accumulation in migratory corridors and channels evaluation (Appendix J of the Background

Compendium) and the water quantity requirements for fish passage alternatives (Appendix K of the Background Compendium), to support the evaluation of alternatives as part of the Volitional Fish Passage Alternatives Development and Evaluation Study.

The following sections compare collected temperature data to maximum optimal temperatures by life stage as described in Appendix N of the Background Compendium. The thermal tolerances provided in Appendix N are mostly used for regulatory purposes. However, from a biological perspective, there is additional context to consider. It is important to note that comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout the Study Area and may be warmer or cooler than shown at other locations. As such, the temperature data that are compared to the thermal tolerances do not account for the presence of microhabitat conditions that could have lower temperature that Chinook Salmon would seek and find. Additionally, recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances suggesting that fish evolve to survive in local thermal conditions (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). Therefore, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

4.2.1 Winnemem Waywaket

As part of the reintroduction and rematriation of Chinook Salmon, the Winnemem Waywaket is expected to provide habitat for spawning, egg incubation, fry emergence, juvenile rearing, and juvenile migration. As such, the temperature data collected as part of this study are compared to the thermal tolerances found in the literature for Chinook Salmon. Temperature data were collected from five locations at The Nature Conservancy and the McCloud Fly Fishing Club in the Winnemem Waywaket over the course of approximately 1 year. More than one TidbiT sensor was installed at each location, so the data from duplicate sensors were averaged by location. To understand the influence of specific tributaries on the seasonal and annual temperature in the Winnemem Waywaket, the five sensor locations were grouped into two stations for the data presentation and analysis: the Ladybug Creek Station and the Claiborne Creek/Yet Atwam Creek Station.

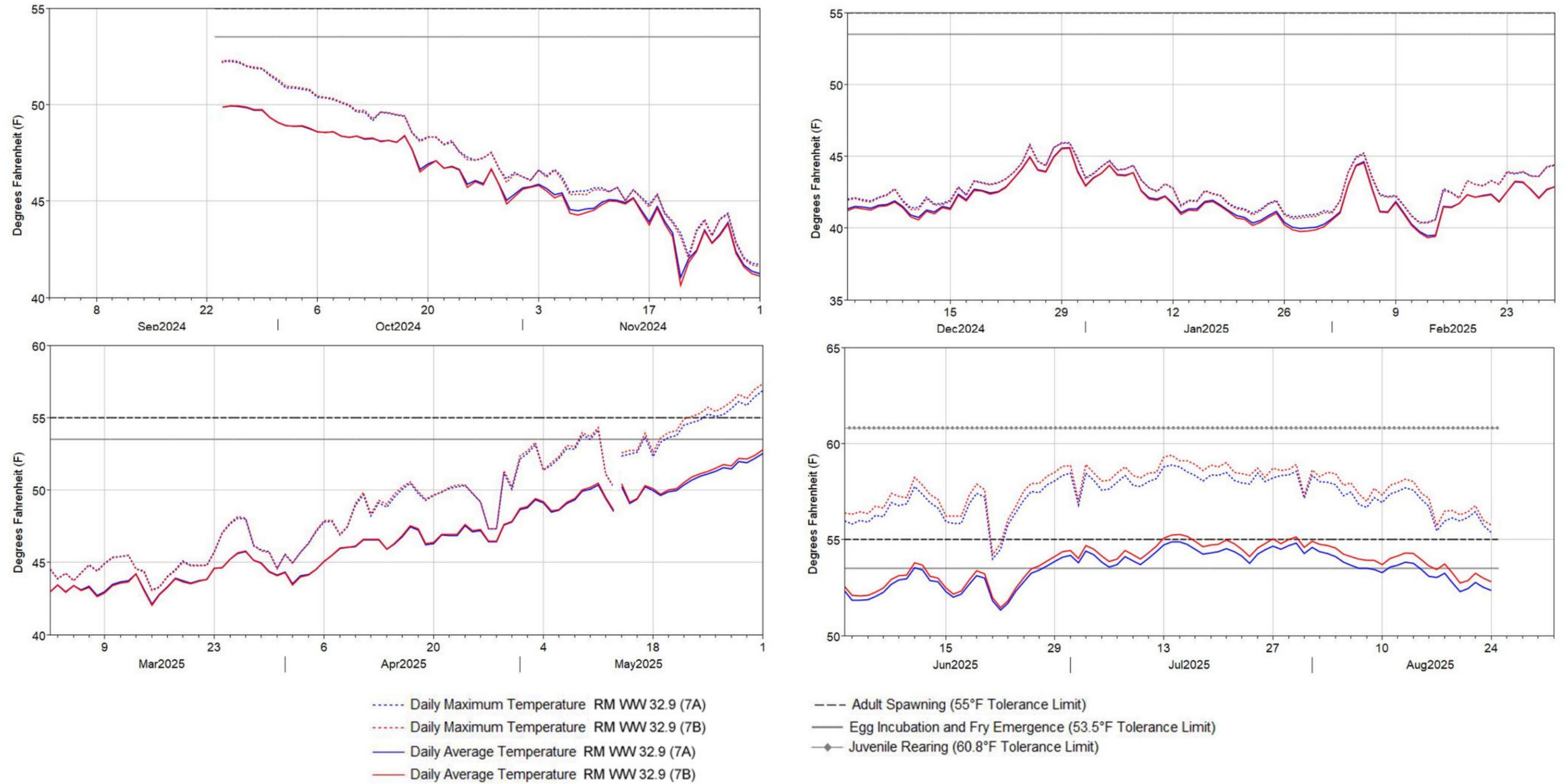
The Ladybug Creek Station consisted of Location 7A (RM 32.9) immediately upstream of Ladybug Creek and Location 7B (RM 32.9) immediately downstream of Ladybug Creek. The daily maximum and daily average temperature are plotted by season in Figure 13, which shows nearly identical temperature (<1°F) at Locations 7A and 7B and indicates little to no effect of Ladybug Creek on the Winnemem Waywaket temperature profile. Figure 14 illustrates that the daily average and daily maximum temperature at both Location 7A and 7B were within approximately 1°F to 3°F throughout the year. Additionally, the daily maximum temperature started to exceed the egg incubation and fry emergence maximum optimal temperature (53.5°F) at this station in late spring (i.e., May 2025) and

continued through the end of the data collection period in late August. No daily maximum or daily average exceeded the juvenile rearing maximum optimal temperature (60.8°F) Seasonal summary statistics based on all logged data are provided in Table 5.

Table 5
Ladybug Creek Station Seasonal Temperature Summary Statistics

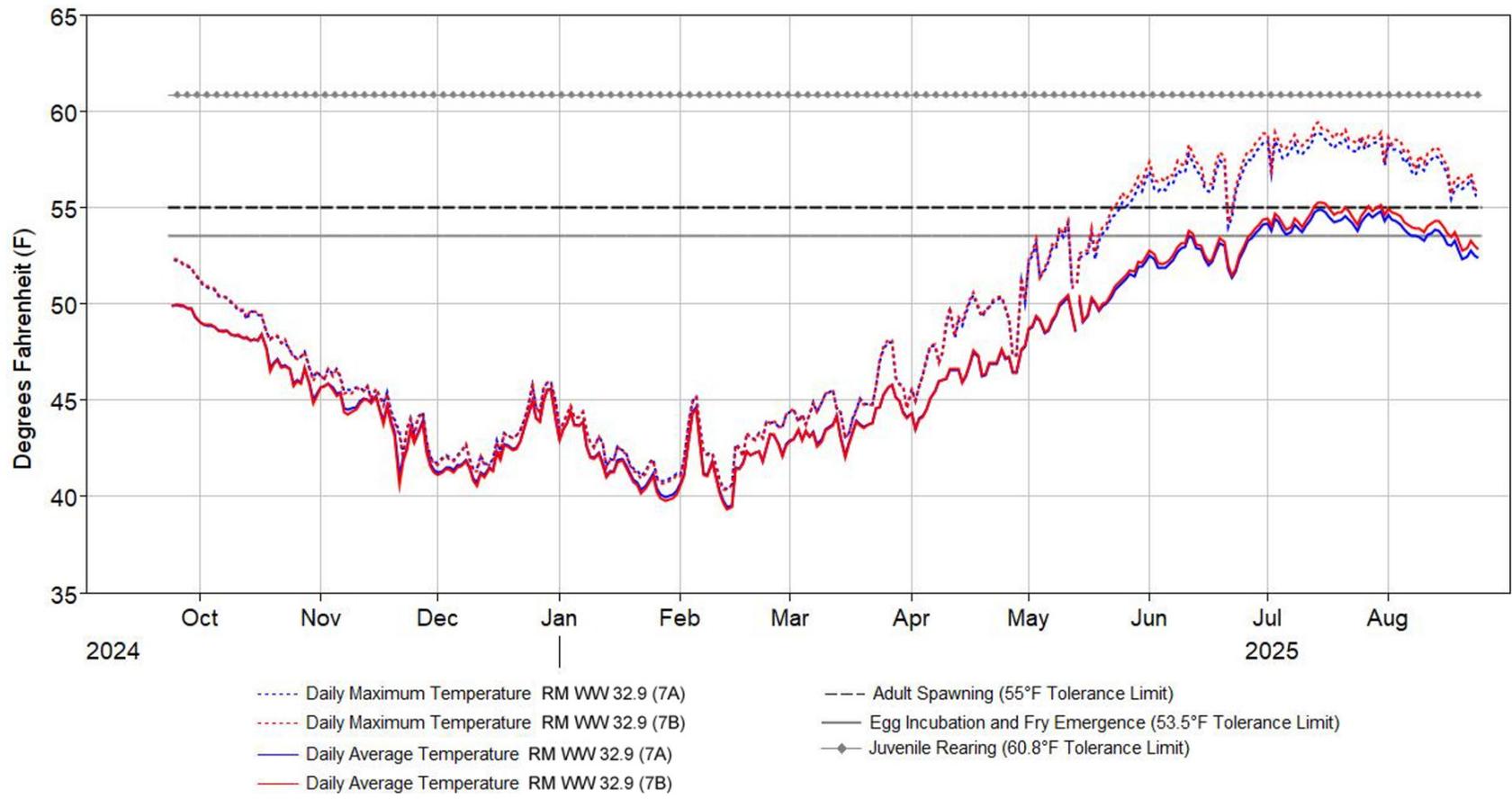
Season	Location ID	Mean (°F)	Median (°F)	Maximum (°F)	Minimum (°F)
Fall	7A	46.15	46.02	52.24	39.45
	7B	46.1	45.95	52.28	38.84
Winter	7A	42.06	41.83	45.93	37.89
	7B	41.98	41.77	45.91	37.75
Spring	7A	47.12	46.79	56.87	41.05
	7B	47.18	46.82	57.35	40.91
Summer	7A	53.46	52.87	58.87	49.03
	7B	53.78	53.21	59.38	49.02

Figure 13
Ladybug Creek Station Seasonal Temperature – Daily Maximum and Daily Average



Note: a) Fall = 09/01/2024 through 11/30/2024; b) Winter = 12/01/2024 through 02/28/2025; c) Spring = 03/01/2025 through 05/31/2025; d) Summer = 06/01/2025 through 08/24/2025

Figure 14
Ladybug Creek Station Annual Temperature – Daily Maximum and Daily Average



The Claiborne Creek/Yet Atwam Creek Station consisted of Location 6B (RM 26.3) immediately upstream of Clairborne Creek, Location 6A (RM 26.1) immediately downstream of Claiborne Creek, and Location 5A (RM 24.2) immediately downstream of Yet Atwam Creek. The daily maximum and daily average temperature are plotted by season on Figure 15, which shows Location 6B is slightly colder (<1°F) than Location 6A and Location 6A is 1°F to 2°F colder than Location 5A. These trends indicate that Claiborne Creek and Yet Atwam Creek may both be contributing slightly warmer water to the Winnemem Waywaket temperature profile. As noted in Section 4.1, based on a review of the data, it was determined that the temperature at Location 6B starting in mid-January indicated the sensor may have been dislodged and was no longer submerged. As a result, those data were excluded from this analysis. Figure 16 illustrates that the daily average and daily maximum temperature at all three locations were within approximately 1°F to 4°F throughout the year. Additionally, the maximum temperature started to exceed the egg incubation and fry emergence maximum optimal temperature (53.5°F) and the adult spawning maximum optimal temperature (55°F) at this set of stations in late spring (i.e., May 2025) and continued through late August when the data collection period ended. The daily maximum temperatures reached or exceeded the juvenile rearing maximum optimal temperature (60.8°F) starting in June and continued into August, with the downstream site of Claiborne Creek being the most consistent to exceed this limit. Only Location 5A had a daily average that briefly exceeded the juvenile rearing maximum optimal temperature during this study. Seasonal summary statistics based on all logged data are provided in Table 6.

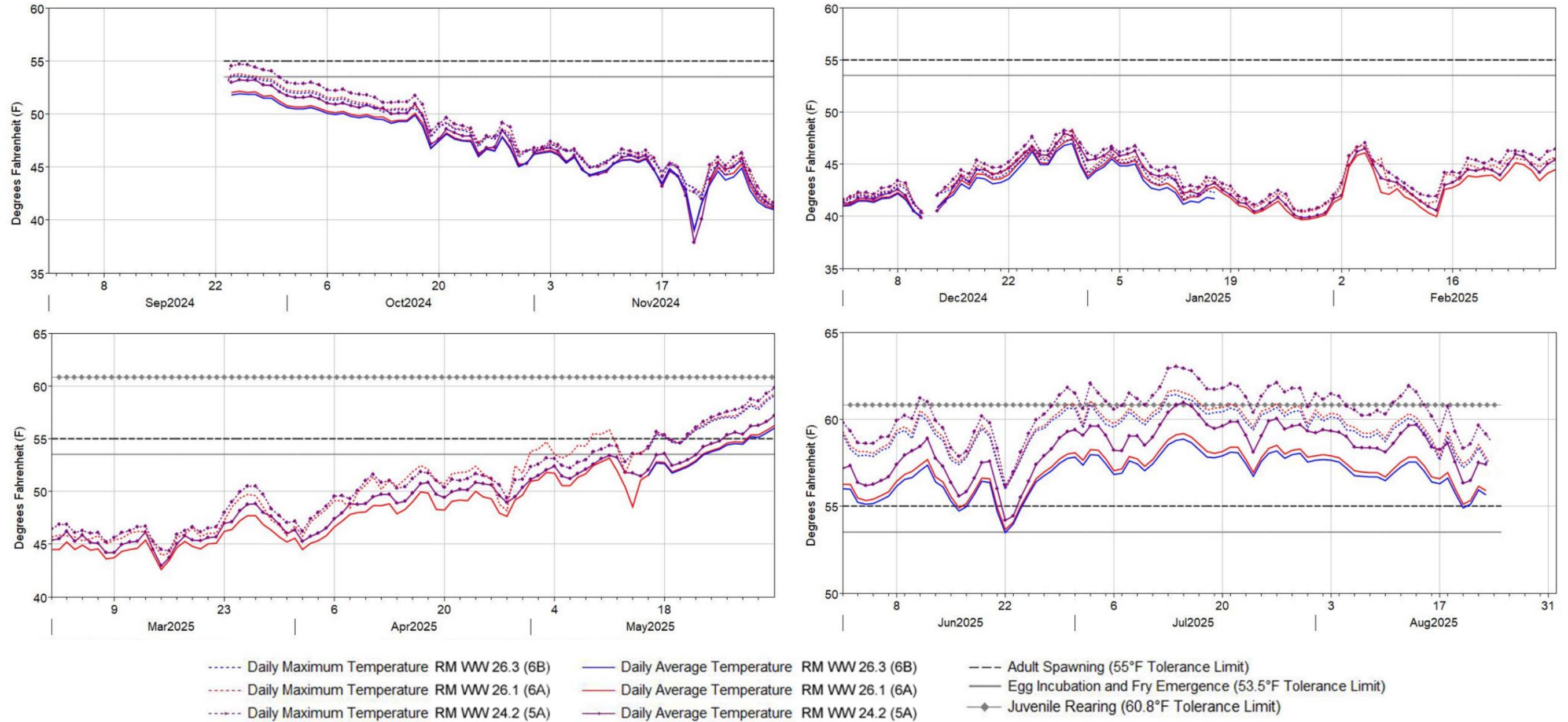
Table 6
Claiborne Creek/Yet Atwam Creek Station Seasonal Temperature Summary Statistics

Season	Location ID	Mean (°F)	Median (°F)	Maximum (°F)	Minimum (°F)
Fall	6B	46.91	46.49	53.64	36.27
	6A	47.05	46.55	53.81	36.05
	5A	47.45	46.79	54.7	35.15
Winter	6B ¹	43.16	42.98	49.81	30.72
	6A	42.54	42.81	49.81	30.72
	5A	42.89	43.13	49.81	30.72
Spring	6B	NA	NA	NA	NA
	6A	47.47	47.02	55.82	41.46
	5A	48.27	48.44	54.33	41.86
Summer	6B	56.79	57.07	61.41	50.30
	6A	57.05	57.31	61.67	50.40
	5A	58.31	58.46	63.02	51.30

Notes:

1. Data analysis represents 12/1/2024 through 01/15/2025, when the sensor appears to have been no longer submerged.
- NA: The statistics could not be calculated due to loss of the sensor.

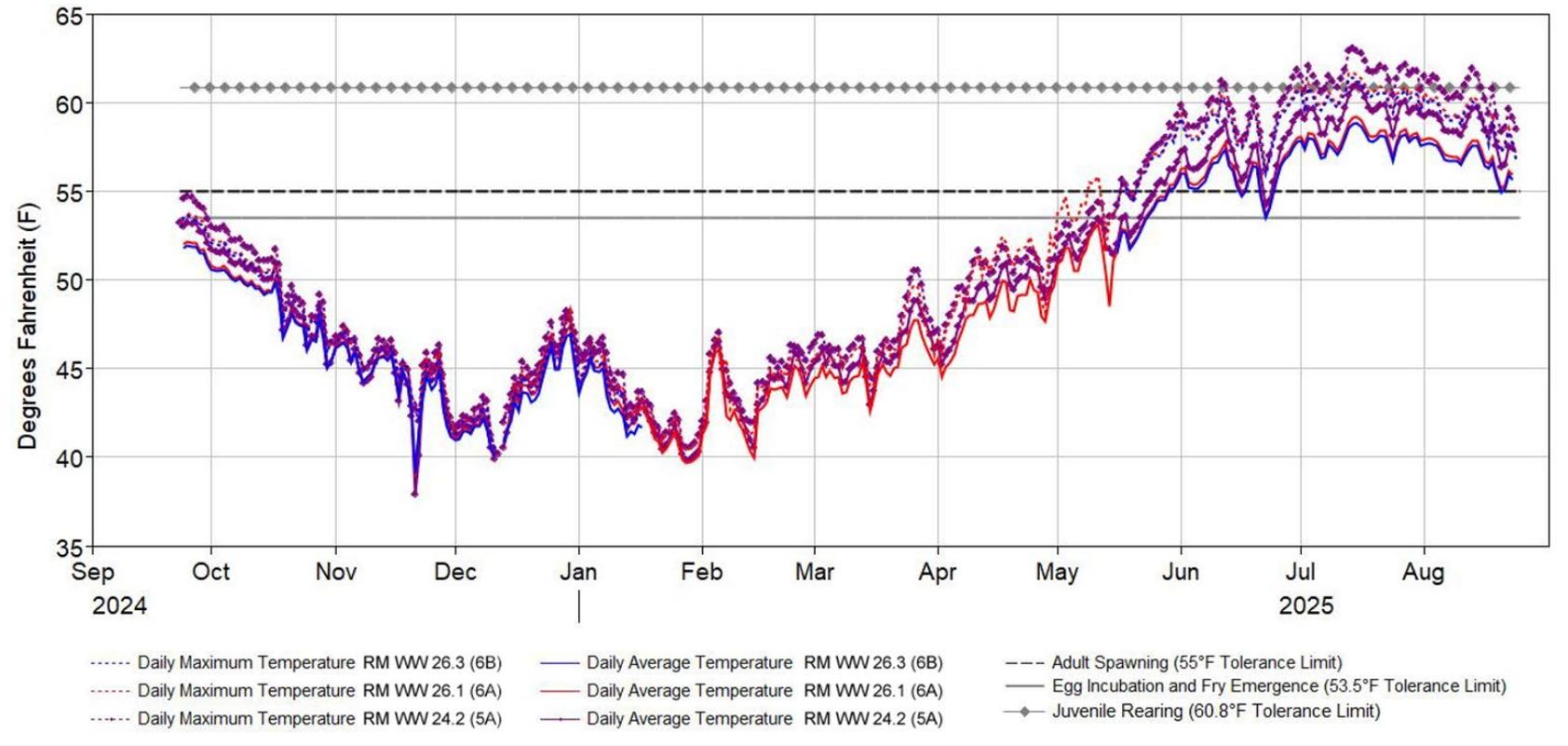
Figure 15
Claiborne Creek/Yet Atwam Creek Station Seasonal Temperature – Daily Maximum and Daily Average



Note: a) Fall = 09/01/2024 through 11/30/2024; b) Winter = 12/01/2024 through 02/28/2025; c) Spring = 03/01/2025 through 05/31/2025; d) Summer = 06/01/2025 through 08/24/2025

Figure 16

Claiborne Creek/Yet Atwam Creek Station Annual Temperature – Daily Maximum and Daily Average



4.2.2 *Shasta Reservoir*

The temperature string in Shasta Reservoir was deployed on September 16, 2024, and recovered on May 15, 2025. Data over this period from the sensors at multiple depths (surface, 1 m, 3 m, 10 m, 20 m, and 40 m) are presented in Figures 17 and 18. As noted in Section 4.1, the 60-m sensor was determined to be inoperable when recovered, so no data for that depth are included in this analysis. Over the duration of the sensor deployment, an anticipated stratification of temperature by depth was identified, with the shallowest sensors being consistently warmer than the deeper sensors. Through the months of mid-November to mid-February, the temperature deviations across depths were minimal in comparison to September through mid-November and mid-March through May. If the deployment had continued through the summer months, it is reasonable to presume that the differences in temperature across depths would be at their highest. As such, the period between March and October was likely when temperature differences between shallow and deep Shasta Reservoir water were the highest. In the hottest months, deeper water in the Shasta Reservoir could serve as thermal refugia for Chinook Salmon when shallower water exceeds thermal tolerances. The end of this seasonal pattern can be seen from mid-September to mid-October before fall storms break up the stratification. Figures 17 and 18 show that the daily maximum and daily average temperature exceeded the juvenile out-migration maximum optimal temperature (64.4°F) in the upper 20 m to 40 m until early November and then starting in the top 1 m by the end of April or beginning of May, indicating that the maximum optimal temperature is likely to be exceeded from the end of April or beginning of May through early November. These figures also show that the daily maximum and daily average temperature exceeded the adult migration maximum optimal temperature (68°F) at this location in the upper 20 m until mid-October and then starting in the top 1 m by early May, making adult migration through the top 20 m of the Shasta Reservoir challenging in the later summer and early fall months.

Figure 17
Continuous Temperature at Shasta Reservoir by Depth – Daily Maximum

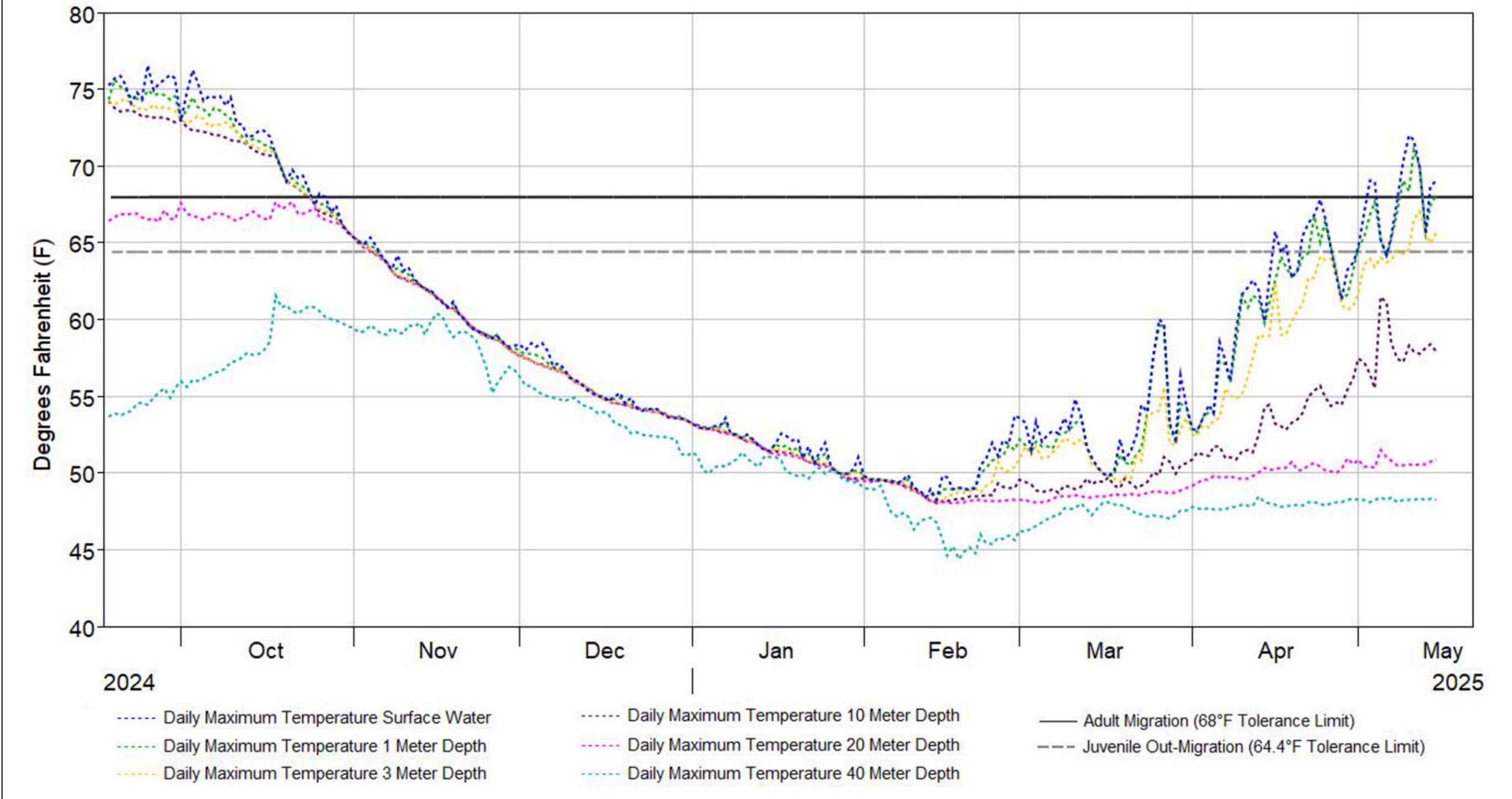
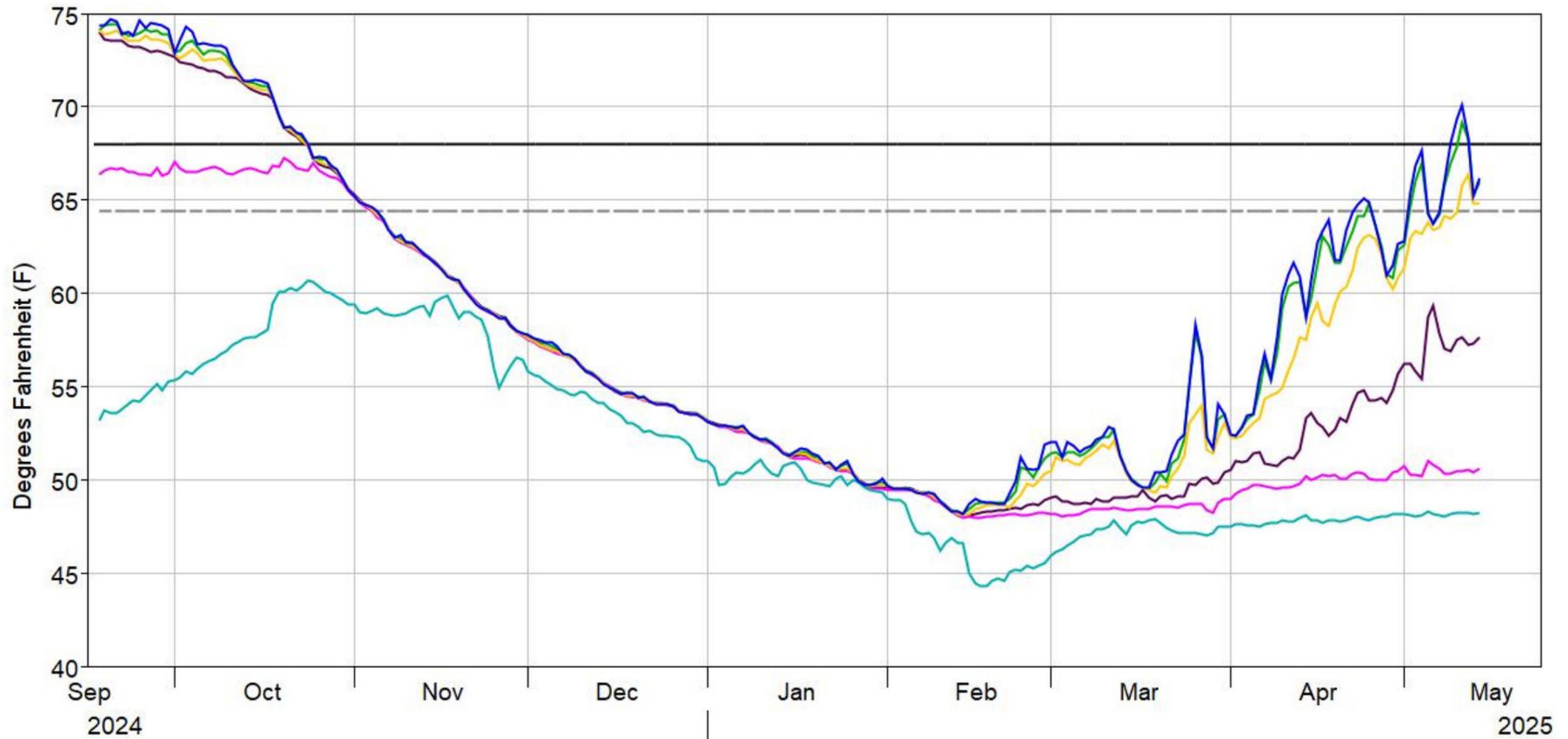


Figure 18
Continuous Temperature at Shasta Reservoir by Depth – Daily Average



- Daily Average Temperature Surface Water
- Daily Average Temperature 1 Meter Depth
- Daily Average Temperature 3 Meter Depth
- Daily Average Temperature 10 Meter Depth
- Daily Average Temperature 20 Meter Depth
- Daily Average Temperature 40 Meter Depth
- Adult Migration (68°F Tolerance Limit)
- Juvenile Out-Migration (64.4°F Tolerance Limit)

4.2.3 *Dry Creek, Little Cow Creek, and Cow Creek*

Through the reintroduction and rematriation of Chinook Salmon, Dry Creek, Little Cow Creek, and Cow Creek (i.e., the migration route), are expected to provide migration, rearing, and staging habitat for both adults and juveniles. As such, the temperature collected as part of this study are compared to the thermal tolerances found in the literature for Chinook Salmon. Temperature and pressure transducer data were collected from five locations (two confluences and one existing gage) over the course of approximately 1 year. More than one U20L sensor was installed at each location, so the data from the duplicate sensors were averaged by location. To understand the seasonal and annual temperature profiles along the migration route in comparison to incoming stream influences along the route, the five sensor locations were grouped into three stations for the data presentation and analysis: the Dry Creek Station, the Little Cow Creek Station, and the Cow Creek/CDFW Gage Station.

4.2.3.1 **Dry Creek Station Temperature**

The Dry Creek Station consisted of Location 3A (RM 12.9) on Dry Creek immediately upstream of the confluence with Little Cow Creek and Location 3B (0.2 RM upstream of the Dry Creek confluence) on Little Cow Creek. The daily maximum and daily average temperature are plotted by season on Figure 19. The figure shows that Dry Creek (Location 3A) was generally 2°F to 4°F cooler than Little Cow Creek until mid-October, when the daily average temperature was similar until early November, when Little Cow Creek was 2°F to 4°F cooler than Dry Creek. As noted in Section 4.1, the sensors at Locations 3A and 3B were dislodged by currents and lost between the December and May data download events; new TidbiT sensors were installed in June to replace the lost sensors. As a result, those data were unavailable for this analysis. The new TidbiT that was installed at Location 3B was missing from its container when the sensors were retrieved in August, resulting in lost data from December through August, 2025. The final week of the deployment of Location 3A data, August 18 through 24, was trimmed due to fluctuations indicative of being out of the water. Figure 20 illustrates that the daily average and daily maximum temperature at both locations was within approximately 1°F to 5°F throughout the year. Additionally, daily maximum and daily average temperature exceeded the juvenile out-migration maximum optimal temperature (64.4°F) until mid-October and then again starting in the spring prior to mid-June on Dry Creek (Location 3A). As such, temperature is likely to exceed the juvenile out-migration maximum optimal temperature from spring through mid-October. These figures also show that the maximum temperature exceeded the adult migration maximum optimum temperature (68°F) through late September and then again starting in the spring prior to mid-June, indicating that temperature is likely to exceed the adult migration tolerance limit from spring through late September. Seasonal summary statistics based on all logged data are provided in Table 7.

Table 7
Dry Creek Station Seasonal Temperature Summary Statistics

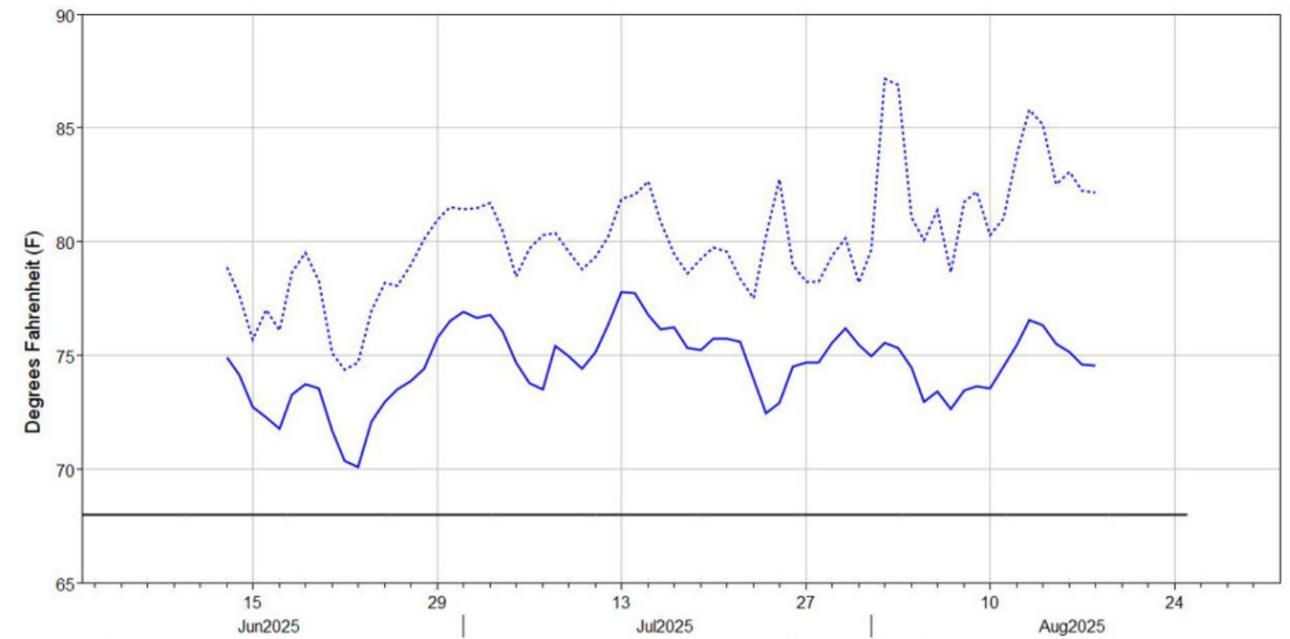
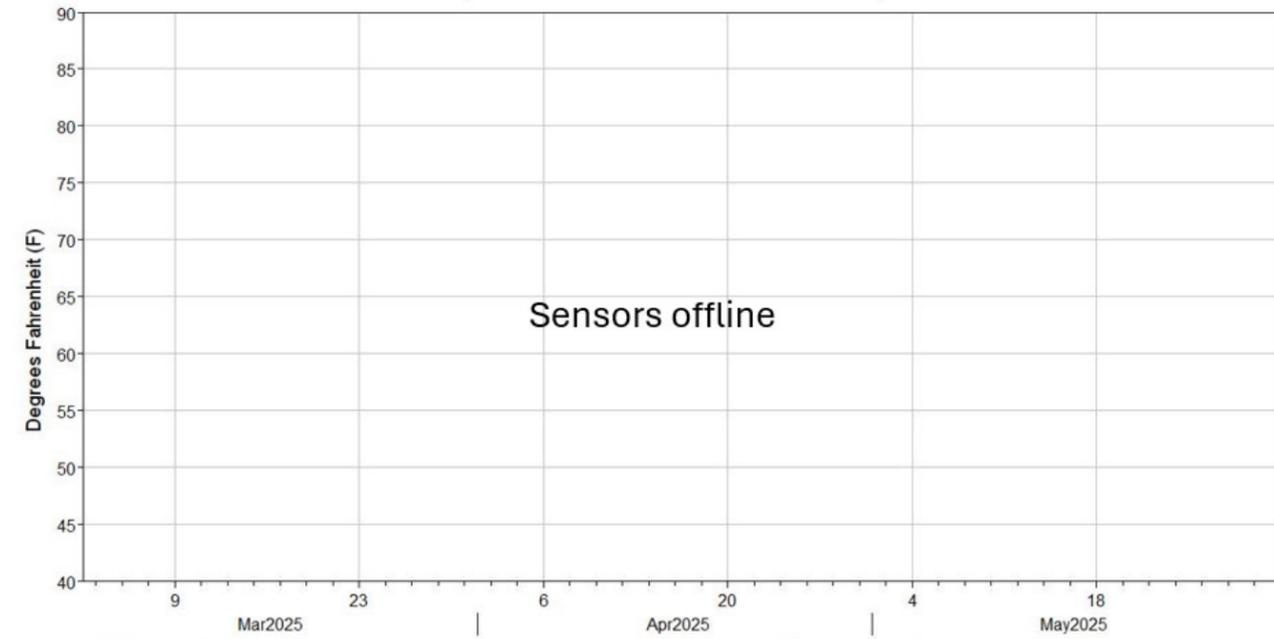
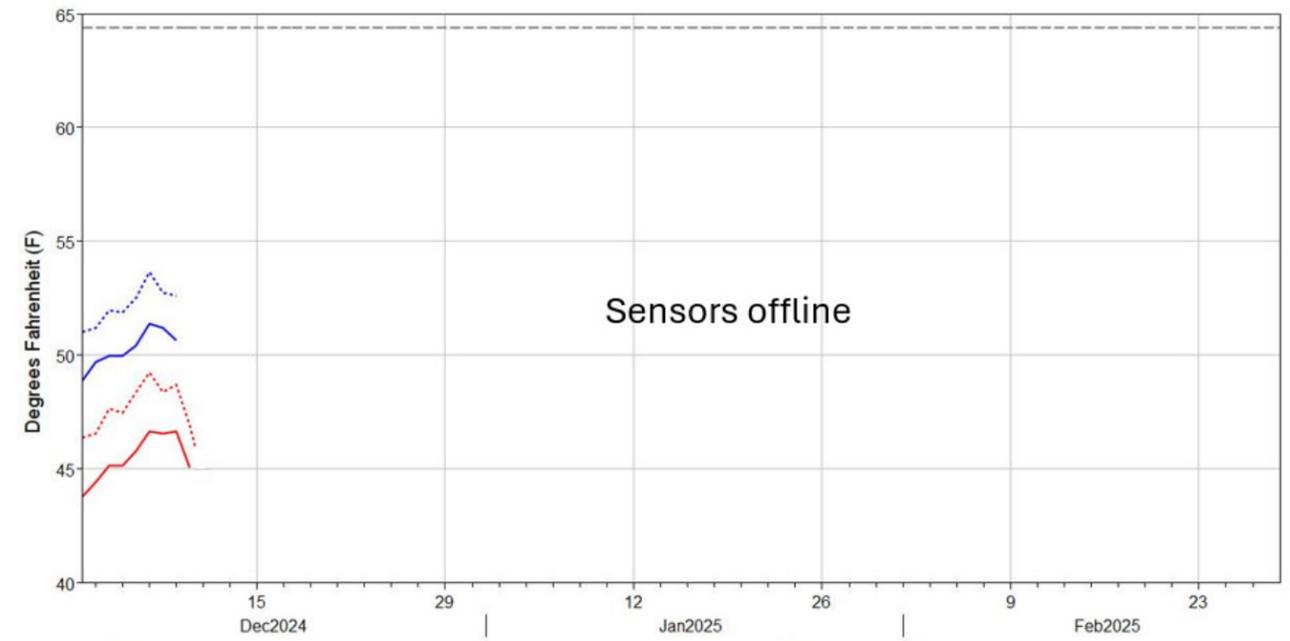
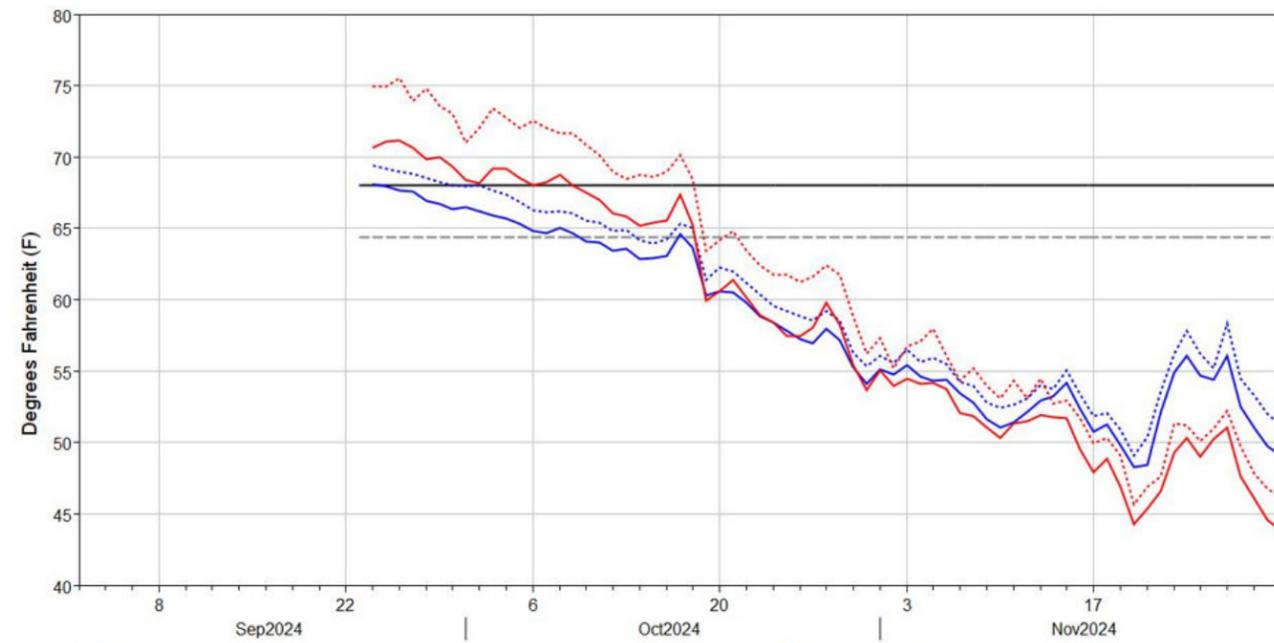
Season	Location ID	Mean (°F)	Median (°F)	Maximum (°F)	Minimum(°F)
Fall	3A	58.26	57.1	69.36	46.55
	3B	58.17	56.75	75.48	41.81
Winter ¹	3A	49.92	49.94	53.62	46.01
	3B	45.25	45.29	49.23	40.7
Spring	3A	NA	NA	NA	NA
	3B	NA	NA	NA	NA
Summer	3A ²	74.58	74.37	87.15	64.83
	3B	NA	NA	NA	NA

Note:

1. Data analysis is through 12/10/2025 due to sensors being lost likely in flash water events.
2. Data analysis is from 06/12/2025 through 08/17/2025. This period is after the TidbiT was installed and had the final week trimmed due to the data suggesting it was out of the water.

NA: The statistics could not be calculated due to loss of the sensor.

Figure 19
Dry Creek Station Seasonal Temperature – Daily Maximum and Daily Average

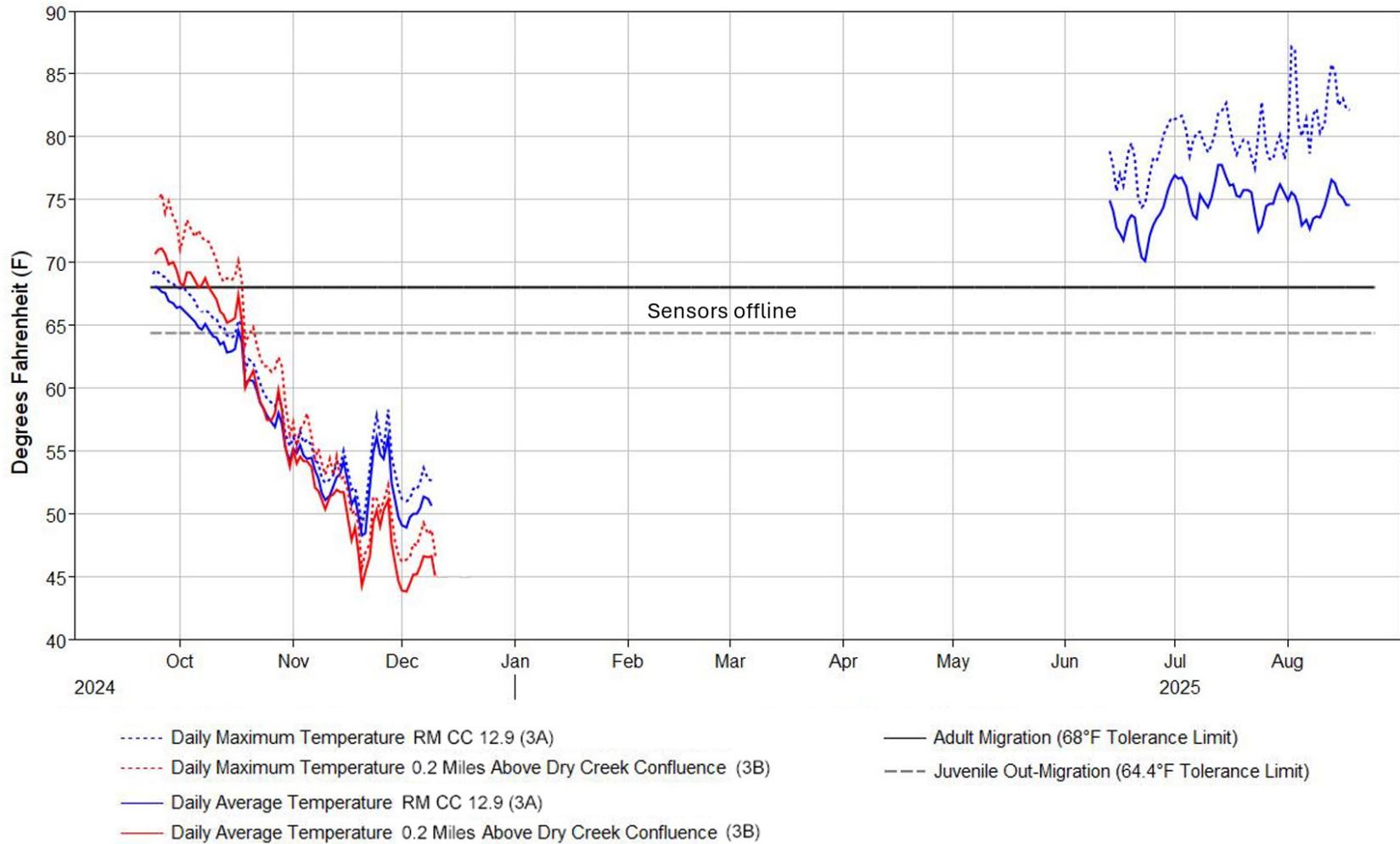


- Daily Maximum Temperature RM CC 12.9 (3A)
- Daily Maximum Temperature 0.2 Miles Above Dry Creek Confluence (3B)
- Daily Average Temperature RM CC 12.9 (3A)
- Daily Average Temperature 0.2 Miles Above Dry Creek Confluence (3B)

- Adult Migration (68°F Tolerance Limit)
- Juvenile Out-Migration (64.4°F Tolerance Limit)

Notes: a) Fall = 09/01/2024 through 11/30/2024; b) Winter = 12/01/2024 through 02/28/2025; c) Spring = 03/01/2025 through 05/31/2025; d) Summer = 06/01/2025 through 08/17/2025

Figure 20
Dry Creek Station Annual Temperature (in Fahrenheit) – Daily Maximum and Daily Average



4.2.3.2 Little Cow Creek Station Temperature

The Little Cow Creek Station consisted of Location 2A (RM 7.6) on Little Cow Creek immediately upstream of the confluence with Cow Creek and Location 2B (0.1 RM upstream of the Little Cow Creek confluence) on Cow Creek. The daily maximum and daily average temperature are plotted by season on Figure 21, which shows Little Cow Creek (Location 2A) was generally 2°F to 4°F warmer than Cow Creek. As noted in Section 4.1, the sensors on Little Cow Creek (Location 2A) were dislodged by currents and lost between the December and May data download events; new TidbiT sensors were installed in June to replace the lost sensors. As a result, those data were unavailable for this analysis. Figure 22 illustrates that the daily average and daily maximum temperature at both locations were within approximately 1°F to 5°F throughout the year. Additionally, daily maximum and daily average temperature exceeded the juvenile out-migration maximum optimal temperature (64.4°F) from the beginning of data collection in mid-September until mid-October and then again starting in early May on Little Cow Creek (Location 2A). As such, it is likely that temperature would exceed the juvenile out-migration maximum optimal temperature starting in early May through late October. These figures also show that the maximum temperature exceeded the adult migration maximum optimal temperature (68°F) until mid-October and then again starting in mid-May indicating that temperature is likely to exceed the adult migration tolerance limit from mid-May through mid-October. Seasonal summary statistics based on all logged data are provided in Table 8.

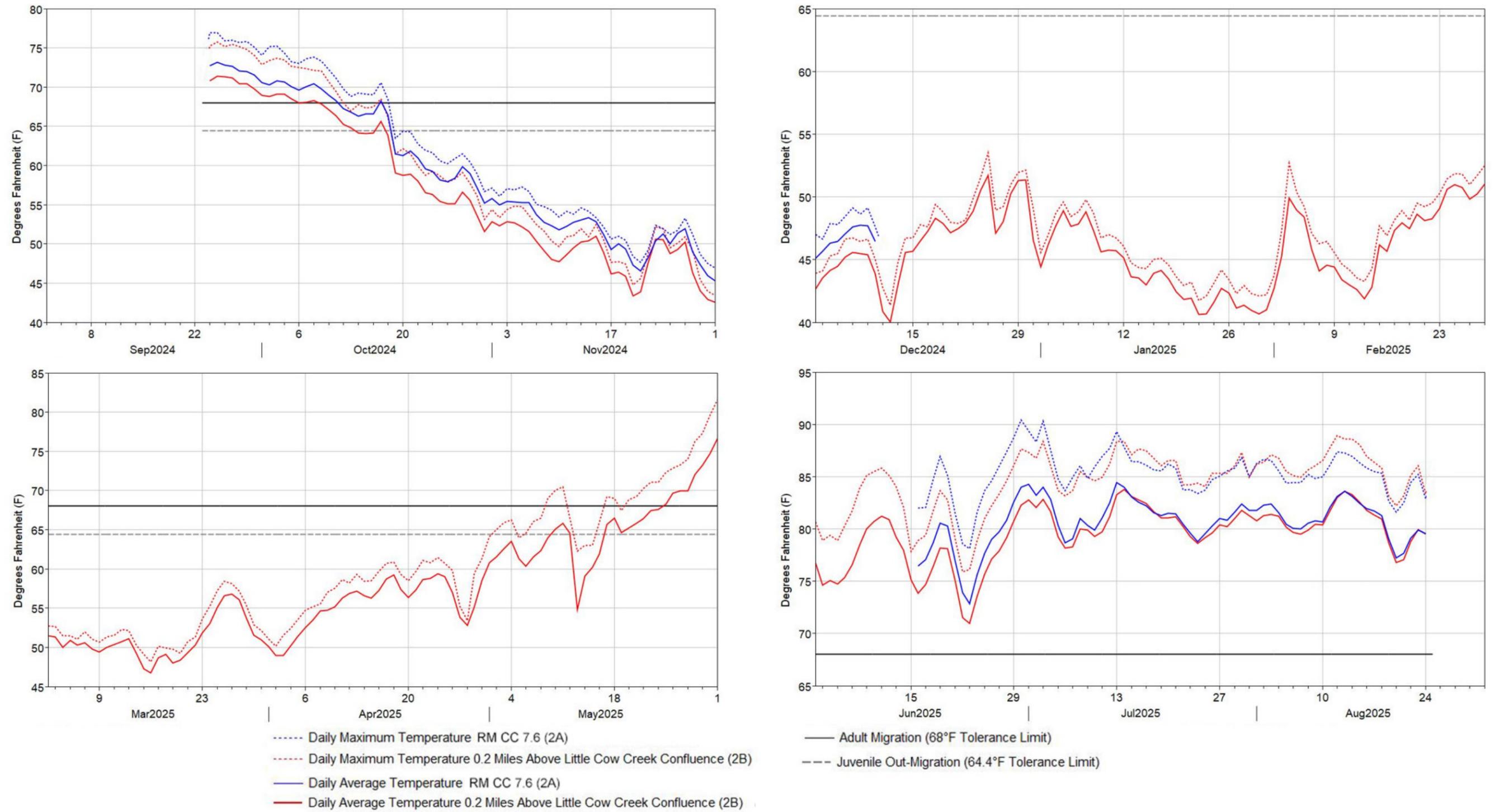
Table 8
Little Cow Creek Station Seasonal Temperature Summary Statistics

Season	Location ID	Mean (°F)	Median (°F)	Maximum (°F)	Minimum (°F)
Fall	2A	59.51	57.74	76.96	43.28
	2B	57.02	54.58	75.75	41.16
Winter	2A	46.52	46.64	49.14	42.82
	2B	45.72	45.65	53.54	38.63
Spring	2A	NA	NA	NA	NA
	2B	57.49	56.58	81.54	45.73
Summer	2A ¹	80.62	80.87	90.41	67.91
	2B	79.45	79.41	88.93	65.75

Note:

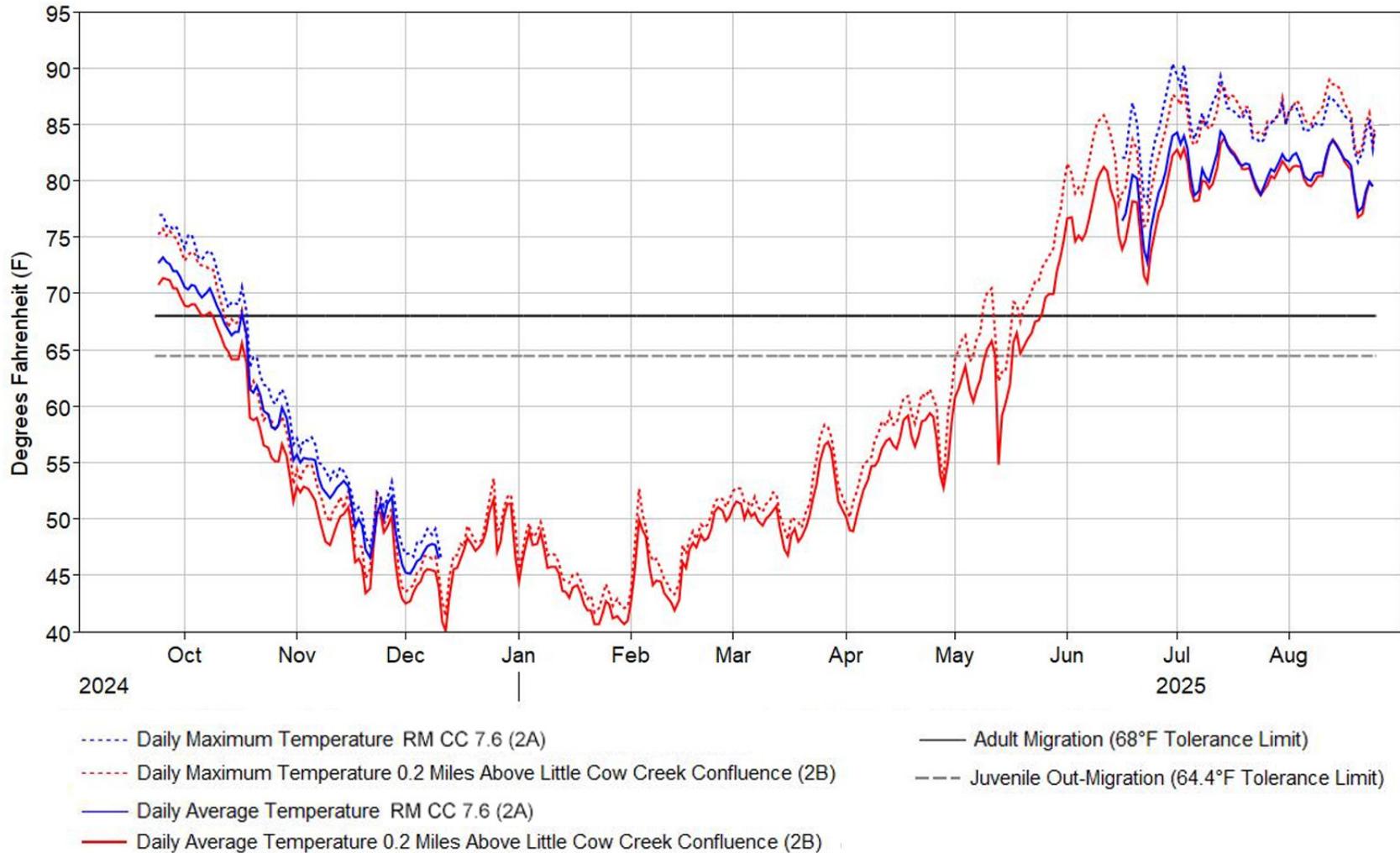
1. Data analysis starts on 06/15/2025 after TidbiT was installed.
- NA: The statistics could not be calculated due to loss of the sensor.

Figure 21
Little Cow Creek Station Seasonal Temperature – Daily Maximum and Daily Average



Notes: a) Fall = 09/01/2024 through 11/30/2024; b) Winter = 12/01/2024 through 02/28/2025; c) Spring = 03/01/2025 through 05/31/2025; d) Summer = 06/01/2025 through 08/24/2025

Figure 22
Little Cow Creek Station Annual Temperature – Daily Maximum and Daily Average



4.2.3.3 Cow Creek Station Temperature

The Cow Creek Station consisted of Location 1A (RM 2.9) on Cow Creek immediately downstream of the Cow Creek near Millville flow gage (USGS 11374000, RM 3.1) and slightly further downstream from the CDFW Cow New Video temperature sensor (RM 4.4) on Cow Creek. The daily maximum and daily average temperature are plotted by season on Figure 23, which shows the new Cow Creek sensor (Location 1A) was generally 1°F cooler than the CDFW sensor. The colder variance in temperature of the downstream Location 1A could be the result of groundwater influence or relative sensor placement in the river (e.g., deeper water, shaded). Figure 24 illustrates that the daily average and daily maximum temperature at both locations was within approximately 1°F to 8°F throughout the year, with slightly more variability in the warmer months. Additionally, daily maximum and daily average temperature exceeded the juvenile out-migration maximum optimal temperature (64.4°F) until mid-October and then again starting in early May on Cow Creek. As such, temperature is likely to exceed the juvenile out-migration maximum optimal temperature from early May through mid-October. These figures also show that the maximum temperature exceeded the adult migration maximum optimal temperature (68°F) until mid-October and then again starting in mid-May, indicating that the tolerance limit is likely to be exceeded from mid-May through mid-October. Seasonal summary statistics based on all logged data are provided in Table 9.

**Table 9
Cow Creek Station Seasonal Temperature (in Fahrenheit) Summary Statistics**

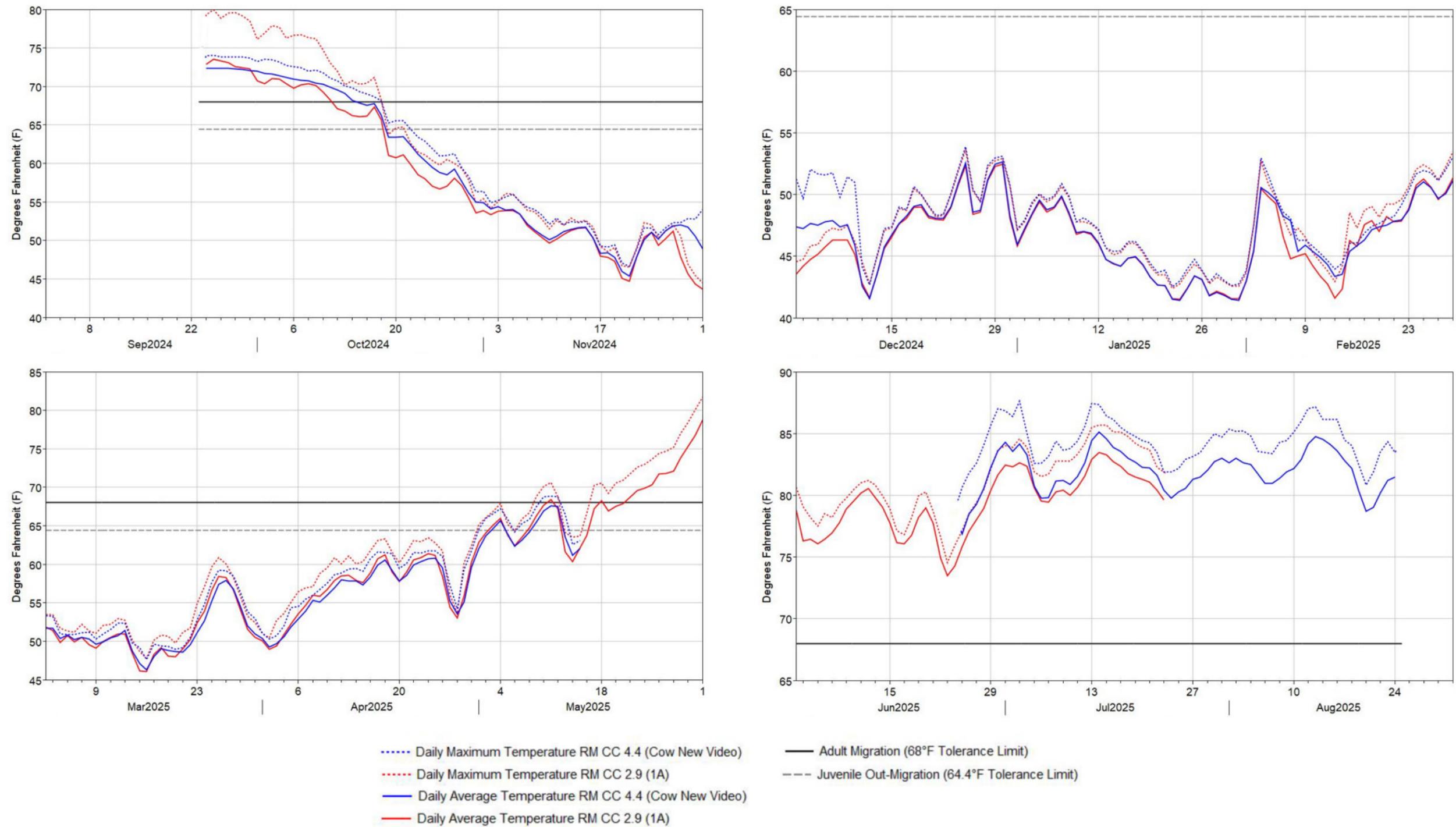
Season	Location ID	Mean (°F)	Median (°F)	Maximum (°F)	Minimum (°F)
Fall	CDFW Sensor	59.70	58.20	74.03	44.58
	1A	58.65	56.23	79.95	42.27
Winter	CDFW Sensor	46.71	47.10	53.87	39.50
	1A	46.36	46.55	53.62	39.95
Spring	CDFW Sensor ¹	55.82	55.47	68.87	45.53
	1A	58.68	58.30	81.72	44.92
Summer	CDFW Sensor ²	81.92	82.00	87.62	73.04
	1A ³	79.32	79.41	85.66	72.28

Note:

2. Data collection ended 05/14/2025 due to sensor buried in the sand.
3. Data collection began on 06/23/2025 due to sensor buried in the sand.
4. Sensor stopped collecting data on 07/24/2025.

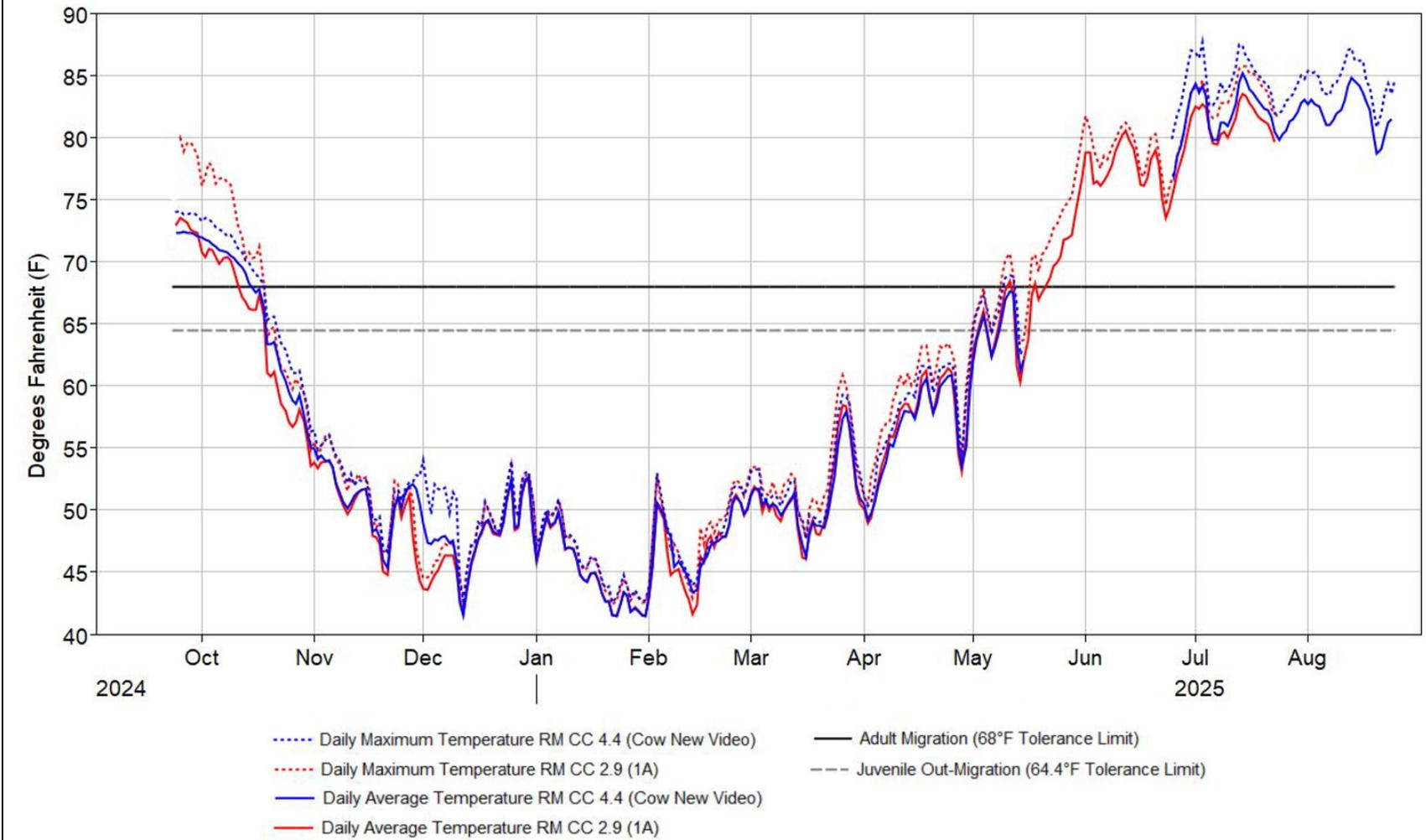
NA: The statistics could not be calculated due to loss of the sensor.

Figure 23
Cow Creek Station Seasonal Temperature – Daily Maximum and Daily Average



Notes: a) Fall = 09/01/2024 through 11/30/2024; b) Winter = 12/01/2024 through 02/28/2025; c) Spring = 03/01/2025 through 05/31/2025; d) Summer = 06/01/2025 through 08/24/2025

Figure 24
Cow Creek Station Annual Temperature – Daily Maximum and Daily Average



4.2.3.4 Dry Creek, Little Cow Creek, and Cow Creek Velocities

A velocity meter was used to collect velocity measurements (at 60% depth) along two transects at each of the three locations along the volitional passage route. The average flow rates calculated from those velocity measurements are presented by location and date in Table 10. The detailed transect data are included in Attachment 5.

Table 10
Average Swoffer Transect Flow Rates by Location During Each Site Visit

Location ID	Installation (September; cfs)	Data Download (December; cfs)	Data Download (June; cfs)	Retrieval ² (August; cfs)
3A	1.78	NA ¹	NA ¹	NA
2A	1.32	0.97	0.78	NA
1A	0.97	0.83	1.41	NA

Note:

1. The presence of a beaver dam at this location prevented water flow and precluded valid Swoffer measurements from being collected.
 2. During the August site visits, an equipment failure prevented all sites from being measured.
- NA: The data could not be collected due to equipment failure.

4.3 Identification of New or Unfilled Data Gaps

Identification of new or unfilled data gaps related to temperature include the following:

- Temperature data for this study were collected in the water column, not subsurface in the substrate. However, effects of water temperature on Chinook Salmon and steelhead productivity can also occur in the redd pocket. Egg-to-alevin survival in the river environment depends largely on redd quality and conditions, including gravel size and composition; surface and intragravel flow, water temperature, and dissolved oxygen; contaminants; sedimentation; and pathogens and diseases (Windell et al. 2017). Temperature-dependent mortality (TDM) of winter-run Chinook Salmon eggs relative to environmental conditions downstream of Keswick Dam has been evaluated and modeled (NOAA 2024; SacPAS 2024). Estimating TDM in the Winnemem Waywaket has not been done and was beyond the scope of this Project. Future work should estimate TDM in the Winnemem Waywaket to inform the winter-run Chinook Salmon life-cycle model.
- Both sensors at Locations 2A and 3A along with the sole sensor at Location 3B became dislodged and were lost sometime between the data download events in December and May. These losses led to an unanticipated data gap spanning from December through June, when replacement temperature sensors were deployed. The resulting lack of continuous temperature data for this period affected the seasonal trend analyses and comparisons described in Section 4.2, and these limitations are documented here for future data

interpretation and use. The canister with the Location 3B sensor deployed in June was recovered without the sensor in August. This further reduces the comparative trends that are able to be made.

- Sensors were installed at high-priority locations along the migration route. Additional monitoring at intermediate sites would improve spatial resolution of stream temperature patterns. Collecting temperature data at more locations between the existing stations would help identify localized thermal variability and provide a more complete understanding of habitat conditions for migration, rearing, and holding. Further, additional sensors downstream of confluences would help assess thermal mixing between the two tributaries and better evaluate the influence of water velocity and volume on temperature.
- For the temperature string in Shasta Reservoir, the sensor deployed at 60 m was inoperable at the time of retrieval, so no temperature data were recovered from the unit. These reservoir temperatures were collected opportunistically and are not critical to this study's objectives; therefore, this represents a minor data gap for understanding the interannual temperature regime below 40 m in the Shasta Reservoir.

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Attachment 1

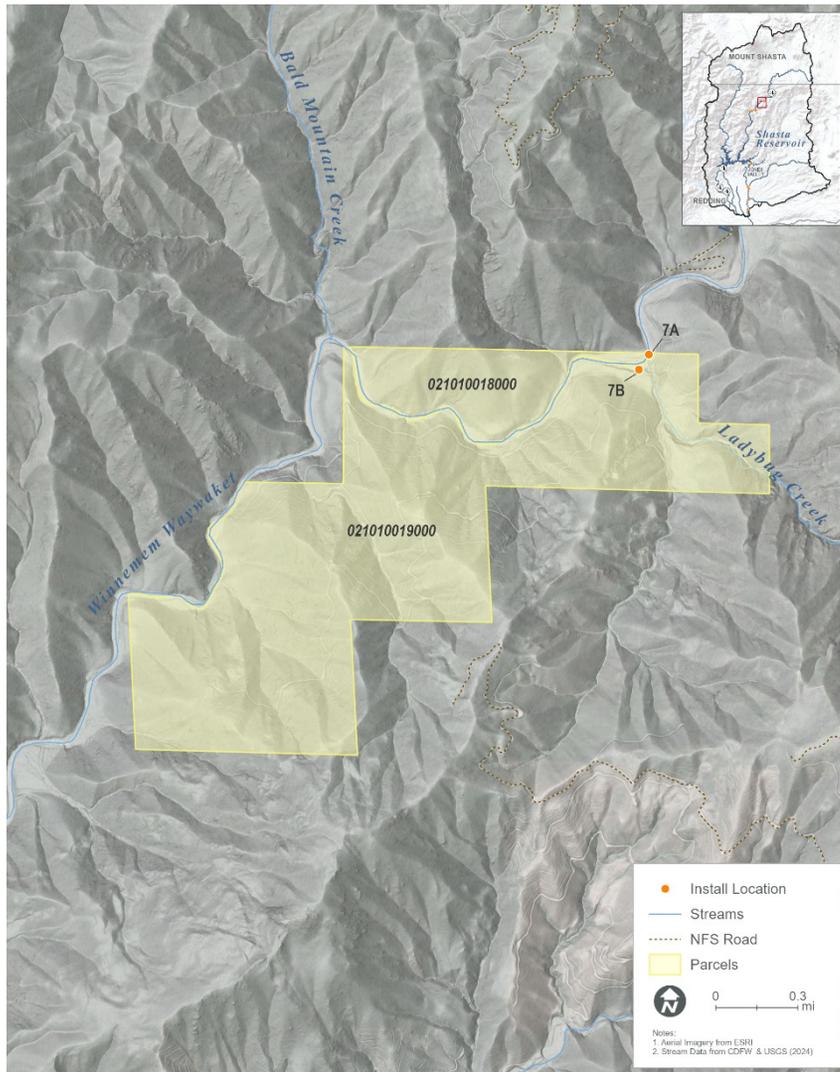
Existing Temperature Data

Provided as Excel files.

Attachment 2

Detailed Site Maps and Photographs

Figure 1
Installation Sites 7A and 7B – The Nature Conservancy

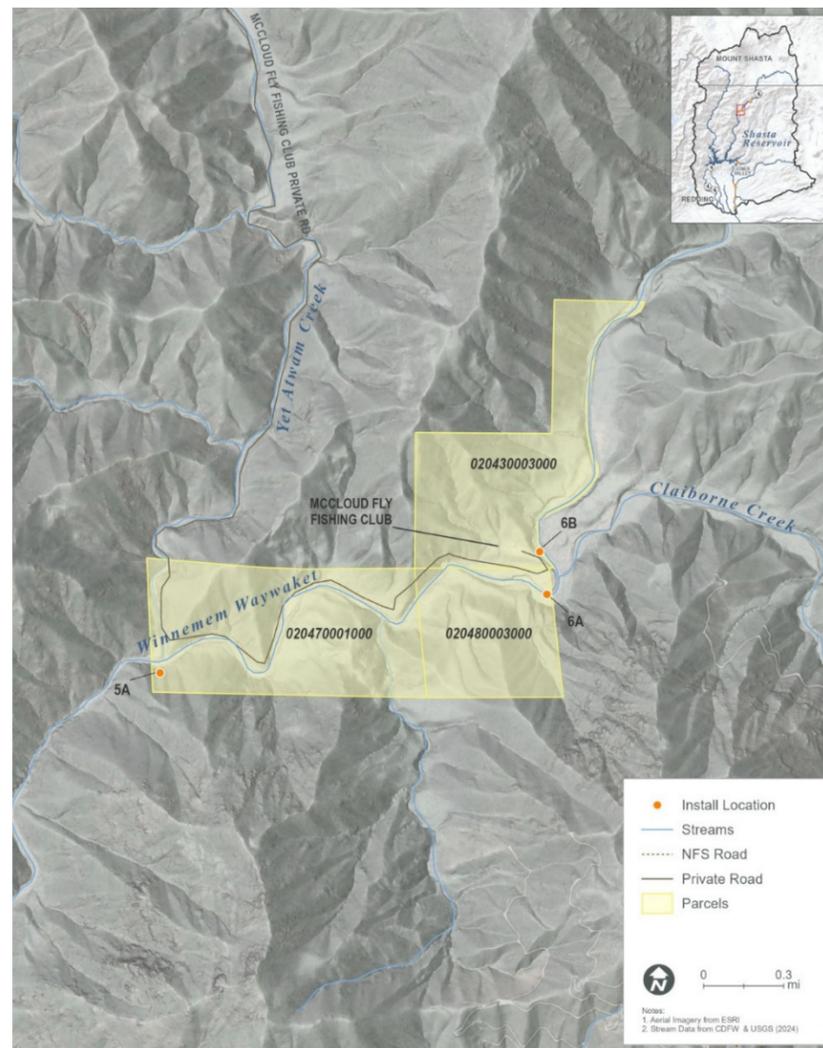


Site 7A - Eastern view facing upstream at sensor install location. Sensors are cabled to rocks among the backwater pools.



Site 7B – Western view facing downstream. Sensors are attached to the permanent USGS gauge installment in the foreground.

Figure 2
Installation Sites 5A, 6A, and 6B – McCloud Fishing Club



Site 6B – Northeast view facing upstream at sensor install location. Sensors are cabled to trees and rocks along a section of streambank.

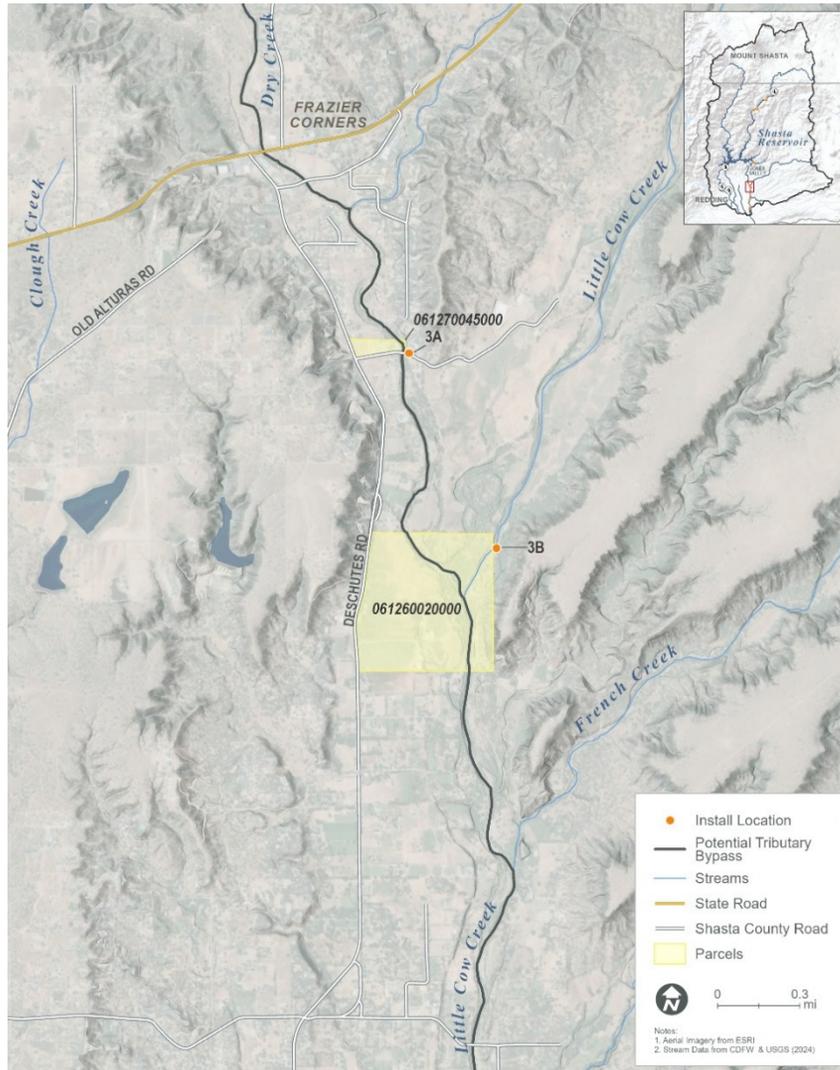


Site 6A – Eastern view facing upstream at sensor install location. Sensors are cabled to the rocks on the left.



Site 5A – Southern view showing stream left bank from sensor install location on stream right. Sensors are cabled to trees and rocks.

Figure 3
Installation Sites 3A and 3B – Dry Creek



Site 3A – Eastern view of sensor at install location. Sensors are cabled to trees and rocks.



Site 3B – Northern view facing upstream at sensor install location. Sensor is attached to a rebar post in the streambed.

Figure 4
Installation Sites 2A and 2B – Little Cow Creek

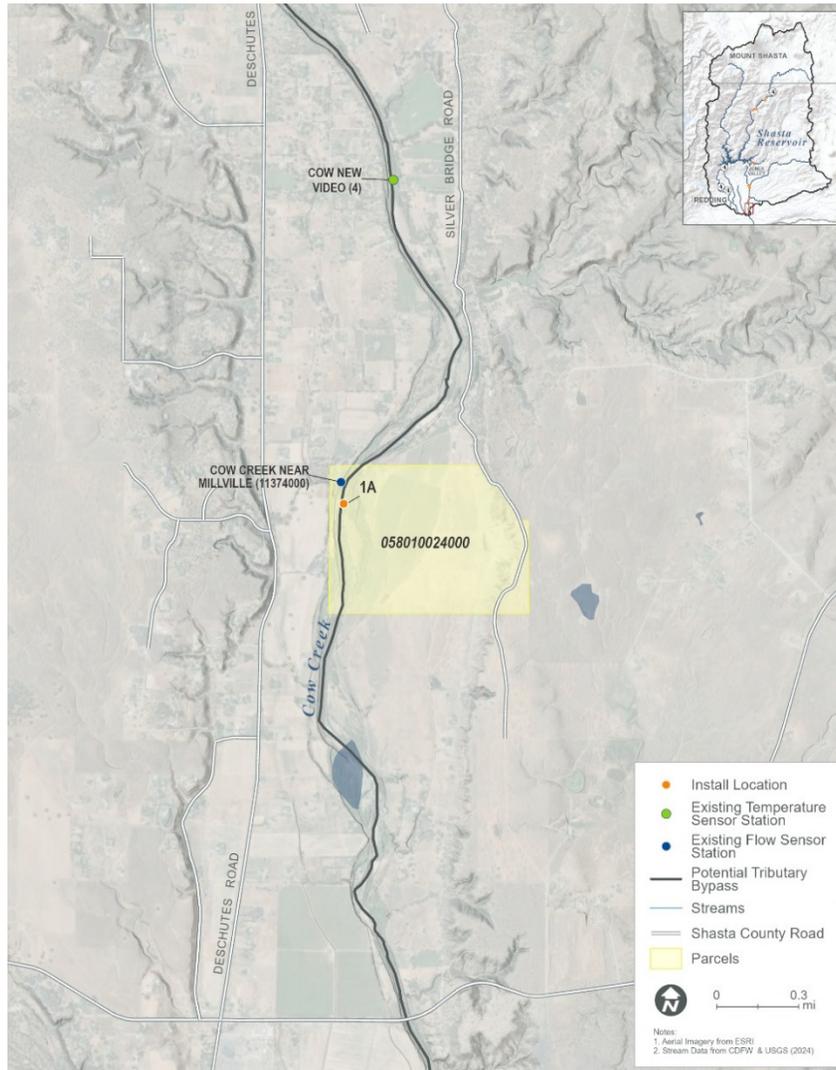


Site 2A – Northern view facing upstream at sensor install location.
 Sensors are cabled to rocks and trees.



Site 2B – Northern view facing upstream at sensor install location.
 Sensors were cabled to the trees on the right.

Figure 5
Installation Site 1A – Cow Creek



Site 1A – Northern view facing upstream at sensor install location.
 Sensors are cabled to rocks and trees.



Site 1A – Southern view facing downstream of sensor install location.

Attachment 3

Stream Temperature and Discharge Data Collection Standard Operating Procedure

Standard Operating Procedure: Stream Temperature and Discharge Data Collection

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EXHIBITS

Exhibit A	Discharge Measurements at Gaging Stations Manual
Exhibit B	HOBO TidbiT MX Temp 400 Manual
Exhibit C	HOBO U20L Water Level Logger Manual
Exhibit D	HOBOconnect User Guide

1 Introduction

This Standard Operating Procedure outlines the protocol for the installation, maintenance, and data download of the HOBO TidbiT MX Temp 400 (TidbiT) temperature logger and U20L Water Level Logger (U20L). The TidbiT uses the HOBObconnect app and Bluetooth features, while the U20L requires a physical connection from a laptop USB to the receiver shuttle and instrument adaptor. Exhibits A through D provide manuals for equipment used for this effort. These efforts are being done to generate temperature and flow data to inform rematriation efforts in the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek.

Note: Check and make sure that all the property owners have been notified prior to going on their property (ideally 1 week in advance).

1.1 Health and Safety

A Health and Safety Plan (HASP) has been developed for this effort. All field activities will be conducted in accordance with the procedures detailed in the HASP.

2 Equipment and Installation

- TidbiT
- U20L
- Mounting accessories (e.g., cables, zip ties, eye bolts, rebar posts, and wire crimping sleeves)
- Mounting tools (drill, 5-pound hammer, wire cutter, and wire crimper)
- Lead weights (to sink or keep the sensors in one place)
- Smartphone or tablet with HOBObconnect app installed
- Tablet or laptop with USB connection and HOBOWare software
- Field notebook with installation and data log forms (forms available in SharePoint)
- GPS
- Phone/camera
- Waders
- Thermometer
- Swiffer current instrument
- Yardstick

2.1 Pre-Installation Activities

These activities should be done prior to entering the field. Double-checking the sensor in the field prior to installation is also recommended.

1. Inspect equipment:
 - a. Check the TidbiT and U20L sensors for any visible damage.
 - b. Ensure the batteries are charged and the sensors turn on.
2. Install HOBObconnect app (available in iOS or Android) on a phone, along with a tablet or computer (tablet or computer is needed for the U20L sensors).
3. Program Sensors:
 - a. Follow the respective HOBOb instrument manual (Exhibits B through D) to connect the sensor via Bluetooth for the TidbiT or physically connect the sensor using the shuttle and USB for the U20L to your device.
 - b. Program the logging interval and start time for the sensor. Do not forget to save these settings.

2.2 Data Logger Installation

1. Survey the bank and identify any potential anchor points (boulder, trees) while taking care to look for hazards such as poisonous oak (property owners have mentioned this on the banks).
 - a. If a site does not have a natural anchor point, embed a rebar/T-post far enough that the post would be secure and not get dislodged by high flows or debris. This could be as little as a few inches but could be much higher. Previous work has driven the post close to the toe of the bank about 1 to 2 feet into the bottom surface (Figure 1).
2. Attach a cable to the anchor point and TidbiT.
3. Secure a lead weight to the TidbiT to help reduce movement during times of higher current.
4. Perform one last verification that all cables and connections are securely fastened and then place the TidbiT or U20L in the desired monitoring location (see image below).
 - a. For the TidbiT, connect from shore via Bluetooth to make sure it is operating correctly.
5. Take a physical depth measurement of the sensor using the yardstick.
 - a. These measurements are critical in the data processing steps.
6. Use the physical thermometer to take a time point 0 measurement and record this in the field notebook.
7. Once installation is completed, a measure of water velocity will be taken using a Swoffer instrument, taking transect measurements adjacent to the temperature sensor.
 - a. Note the location of the transect, as Swoffer measurements will be repeated at the same spot—or as close as conditions allow—during data downloads.
 - b. Follow Exhibit A for guidance on number of measurements and increments

Figure 1
Example TidbiT installation



2.3 Data Download

1. Wade out to the sensor and take a depth measurement with the yardstick.
 - a. This measurement is critical to processing the data for the U20L instruments.
2. Carefully retrieve the U20L data logger and inspect the sensor for any damage since the initial installation.
 - a. A visual inspection can be done of the TidbiT without removal.
3. Connect the U20L sensor to your computer using the shuttle and HOBOWare Pro software.
 - a. HOBObconnect can be used onshore to connect to the TidbiT.
 - b. Open the app, make sure Bluetooth is on, and follow the instructions to connect.
4. Download data:
 - a. Save the data files with clear and descriptive names (e.g., location and date range), along with filling out the data log forms downloaded from SharePoint.

- b. Verify the data for completeness and accuracy.
 - c. Once back to an area with steady internet, backup all files onto SharePoint every night.
5. Redeploy the U20L sensor
 - a. Check that the condition of the sensor and make sure it is suitable for redeployment and does not need to be replaced.
 - b. Check the battery level is also suitable for redeployment and address if necessary.
 - c. Make a final physical depth measurement of the redeployed U20L sensor and include these measurements in the uploaded field notes.
6. Once reinstallation is complete, a measure of water velocity will be taken using a Swoffer instrument, taking transect measurements adjacent to the temperature sensor.
 - a. If river conditions permit, the measurements should be replicated at the exact location of the previous Swoffer transect or as close to that location as possible.
7. Take a temperature measurement using the packed thermometer.

2.4 Device Removal

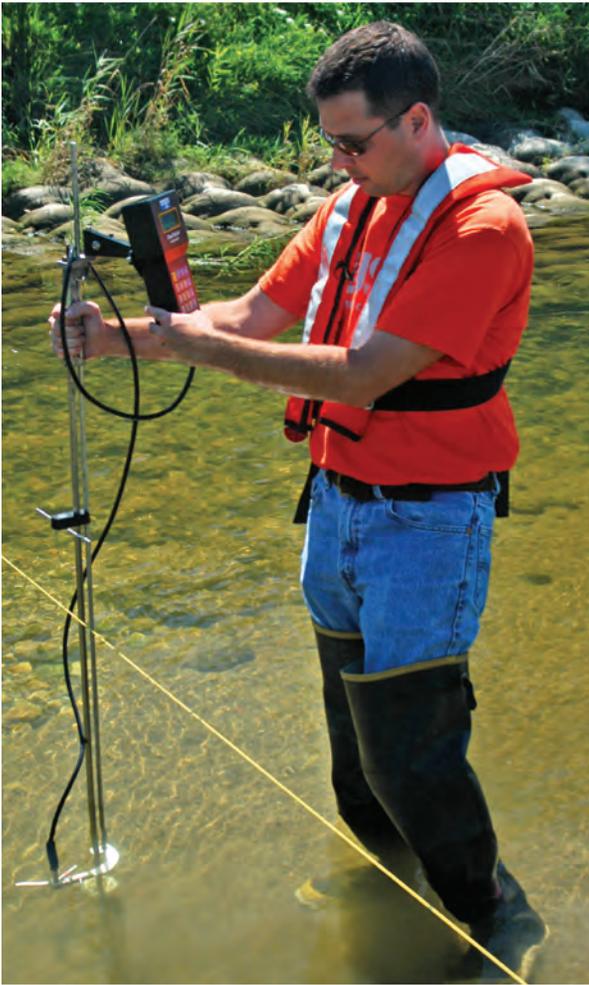
1. Measure the depth at the sensor using a yardstick.
2. After the final sensor depth measurement is completed, carefully remove the temperature sensors and perform the final data download.
3. The sensor can be shut off after the data is downloaded and checked for completeness.
4. Disconnect all cables, and if rebar was installed, it will need to be removed taking care not to damage any property.
5. One final current measurement should be taken using a Swoffer instrument at or as near to the original transect as possible.
6. Take a measure of the temperature using the packed thermometer.
7. Upload all data and measurements to the SharePoint.

Exhibit A

Discharge Measurements at Gaging
Stations Manual

Discharge Measurements at Gaging Stations

Chapter 8 of Book 3, Section A



Techniques and Methods 3–A8

Front cover: On the left, photograph of a USGS hydrographer making a FlowTracker acoustic Doppler velocimeter discharge measurement at Little Eagle Creek at Speedway, Ind. (USGS station no. 03353600); on the right, photograph of a USGS hydrographer making a tethered boat acoustic Doppler current profiler discharge measurement from a cableway at the Snake River near Moran, Wyo. (USGS station no. 13011000).

Back cover: In the background, 1890 black and white photograph of USGS hydrographers making a mechanical current meter discharge measurement from a cableway at the Arkansas River near Canyon City, Colo. (USGS station no. 07096000); and on the right, 1958 black and white photograph of a USGS hydrographer making a mechanical current meter discharge measurement at the Cedar River at Belgrade, Nev. (USGS station no. 06791800).

Discharge Measurements at Gaging Stations

By D. Phil Turnipseed and Vernon B. Sauer

Techniques and Methods 3–A8

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

U.S. Department of the Interior
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Preface

This series of manuals on techniques and methods (TM) describes approved scientific and data-collection procedures and standard methods for planning and executing studies and laboratory analyses. The material is grouped under major subject headings called “books” and further subdivided into sections and chapters. Section A of book 3 is on surface-water techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. These publications are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment, and this format permits flexibility in revision and publication as the need arises. Chapter A8 of book 3 (TM 3–A8) deals with discharge measurements at gaging stations. The original version of this chapter was published in 1969 as U.S. Geological Survey (USGS) Techniques for Water-Resources Investigations, chapter A8 of book 3. New and improved equipment, as well as some procedural changes, have resulted in this revised second edition of “Discharge measurements at gaging stations.”

This edition supersedes USGS Techniques of Water-Resources Investigations 3A–8, 1969, “Discharge measurements at gaging stations,” by T.J. Buchanan and W.P. Somers, available at <http://pubs.usgs.gov/twri/twri3a8/>, and supplements USGS Water-Supply Paper 2175, volume 1, 1982, “Measurement and computation of streamflow: Measurement of stage and discharge,” by S.E. Rantz and others, available at http://pubs.usgs.gov/wsp/wsp2175/html/WSP2175_voll.html.

This revised second edition of “Discharge measurements at gaging stations” is published online at <http://pubs.usgs.gov/tm/tm3-a8/> and is for sale by the U.S. Geological Survey, Science Information Delivery, Box 25286, Federal Center, Denver, CO 80225.

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Conversion Factors

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m ²)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm ²)
acre	0.004047	square kilometer (km ²)
square foot (ft ²)	929.0	square centimeter (cm ²)
square foot (ft ²)	0.09290	square meter (m ²)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m ³)
gallon (gal)	3.785	cubic decimeter (dm ³)
million gallons (Mgal)	3,785	cubic meter (m ³)
cubic foot (ft ³)	28.32	cubic decimeter (dm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
acre-foot (acre-ft)	1,233	cubic meter (m ³)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm ³)
Flow rate		
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m ³ /s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m ³ /yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm ³ /yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second per square kilo- meter [(m ³ /s)/km ²]
cubic foot per day (ft ³ /d)	0.02832	cubic meter per day (m ³ /d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m ³ /d)
gallon per day per square mile [(gal/d)/mi ²]	0.001461	cubic meter per day per square kilometer [(m ³ /d)/km ²]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m ³ /s)
million gallons per day per square mile [(Mgal/d)/mi ²]	1,461	cubic meter per day per square kilome- ter [(m ³ /d)/km ²]
Mass		
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Multiply	By	To obtain
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound-force per square inch (lbf/in ²)	6.895	kilopascal (kPa)
pound per square foot (lb/ft ²)	0.04788	kilopascal (kPa)
pound per square inch (lb/in ²)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft ³)	16.02	kilogram per cubic meter (kg/m ³)
pound per cubic foot (lb/ft ³)	0.01602	gram per cubic centimeter (g/cm ³)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Vertical Datum of 1988 (NAVD 88)."

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Datum of 1983 (NAD 83)."

Elevation, as used in this report, refers to distance above sea level. Because this report is based on a large number of previously published scientific investigations, "sea level" is not referenced to a single vertical datum. "Mean sea level" also is not used with reference to a single datum; where used, the phrase means the average surface of the ocean as determined by calibration of measurements at tidal stations.

Abbreviations and Acronyms

AA	Price AA current meter
ADCP	acoustic Doppler current profiler
ADC	acoustic digital current meter
ADV	acoustic Doppler velocimeters
Aquacalc	JBS Instruments Aquacalc Pro Discharge Measurement Computer
C1	C1 connector
CMD	current meter digitizer
CMCsp	Hydrological Services Current Meter Counter signal processor
CSG	crest stage gage
CST	Central Standard Time
C type	Columbus type
DCP	Data Collection Platform
DGPS	global positioning system with differential corrections
dB	decibels
EDT	Eastern Daylight Time

EFN	electronic field notebook
EST	Eastern Standard Time
FlowTracker	SonTek/YSI FlowTracker Handheld acoustic Doppler velocimeter
GPS	global positioning system
HIF	U.S. Geological Survey Hydrologic Instrumentation Facility
HWM	high water mark
Hz	hertz
ISO	International Organization for Standardization
kHz	kilohertz
LEW	left edge of water
MHz	megahertz
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NWIS	U.S. Geological Survey National Water Information System
OFR	U.S. Geological Survey Open-File Report
PDA	portable digital assistant
PFD	personal flotation device
QA/QC	quality assurance and quality control
RD	Teledyne RD Instruments
REW	right edge of water
RP	reference point
RTK	real-time kinematic
RTK-GPS	real-time kinematic global positioning system
SNR	signal-to-noise ratio
SWAMI	surface water measurement and inspection
TM	U.S. Geological Survey Techniques and Methods
TRDI	Teledyne RD Instruments
TWRI	U.S. Geological Survey Techniques of Water-Resources Investigations
USGS	U.S. Geological Survey
WAAS	Wide Area Augmentation System
WRD	Water Resources Division/Discipline
WSC	Water Science Center
WSCan	Environment Canada Ministry Water Survey of Canada Agency

Definitions of Symbols

a_i	cross-section area for the i th segment of the n segments into which the cross section is divided
arctan	arctangent
b	width of the throat section (in units of distance)
b_j	distance from initial point to location i
$b_{(i-1)}$	distance from initial point to preceding location
$b_{(i+1)}$	distance from initial point to next location
d_i	depth of water at location i
C	coefficient of discharge

<i>c</i>	speed of sound (in distance per unit time)
cos	cosine of the angle alpha
°C	temperature in degrees Celsius
CORR_{wl}	correction (in units of distance) to subtract from the wet-line depth to obtain the vertical depth
D_{wl}	wet-line depth (in units of distance)
D_v	vertical depth (in units of distance)
	average change in stage in the reach <i>L</i> during the measurement (in units of distance)
	elapsed time during measurement
	computed phase difference
°F	temperature in degrees Fahrenheit
<i>H</i>	weighted mean gage height (in units of distance)
<i>h</i>	static head, head, elevation, or gage height (in units of distance)
IQR	interquartile range
<i>L</i>	length of reach between measuring section and control (in units of distance)
<i>m</i>	difference (in feet) between the air-line correction for the sounding position and that for the 0.8 position
<i>n</i>	difference (in feet) between the wet-line correction for the sounding position and that for the 0.8 position, if the depths are greater than 40 feet and the change in vertical angle is more than 5 percent
<i>P</i>	vertical angle (in degrees)
	ratio of the circumference to the diameter of a circle; approximately equal to 3.14159
<i>Q</i>	discharge (in volume per unit time)
<i>Q1</i>	25 percent of samples are less than this value
<i>Q3</i>	75 percent of samples are less than this value
<i>q_i</i>	discharge through partial section <i>i</i> , (in volume per unit time)
<i>R</i>	number of rotor revolutions per second
<i>T</i>	total time for the measurement
<i>t_i</i>	duration of time intervals between breaks in the slop of the gage height graph
tan	tangent
	time lag between pulses
<i>V</i>	velocity (in distance per unit time)
<i>V_x</i>	velocity (in distance per unit time) in the <i>x</i> direction (perpendicular to the tag line)
<i>V_y</i>	velocity (in distance per unit time) in the <i>y</i> direction (parallel to the tag line)
<i>V</i>	volume of water in container
<i>v_i</i>	mean velocity (in units of distance per unit time) of the flow normal to the <i>i</i> th segment, or vertical
<i>W</i>	average width of stream between measuring section and control (in units of distance)
<i>W₁</i>	weight of empty container (in units of mass)
<i>W₂</i>	weight of container with water (in units of mass)
<i>w</i>	unit weight of water (in units of mass per volume)
<i>x</i>	<i>x</i> -direction (perpendicular to the tag line) or <i>x</i> -component of velocity

Discharge Measurements at Gaging Stations

By D. Phil Turnipseed and Vernon B. Sauer

Abstract

The techniques and standards for making discharge measurements at streamflow gaging stations are described in this publication. The vertical axis rotating-element current meter, principally the Price current meter, has been traditionally used for most measurements of discharge; however, advancements in acoustic technology have led to important developments in the use of acoustic Doppler current profilers, acoustic Doppler velocimeters, and other emerging technologies for the measurement of discharge. These new instruments, based on acoustic Doppler theory, have the advantage of no moving parts, and in the case of the acoustic Doppler current profiler, quickly and easily provide three-dimensional stream-velocity profile data through much of the vertical water column. For much of the discussion of acoustic Doppler current profiler moving-boat methodology, the reader is referred to U.S. Geological Survey Techniques and Methods 3–A22 (Mueller and Wagner, 2009).

Personal digital assistants (PDAs), electronic field notebooks, and other personal computers provide fast and efficient data-collection methods that are more error-free than traditional hand methods. The use of portable weirs and flumes, floats, volumetric tanks, indirect methods, and tracers in measuring discharge are briefly described.

Purpose and Scope

The U.S. Geological Survey (USGS) makes tens of thousands of streamflow measurements each year across the United States and its territories. Measured discharges range from a trickle in a small ditch or stream [less than 0.01 cubic foot per second (ft^3/s)], to a flood on the Mississippi River (greater than 1,800,000 ft^3/s). Several methods are used by the USGS to make streamflow measurements. Principally, the USGS uses mechanical current meters and hydroacoustic meters [for example, acoustic Doppler current profilers (ADCPs) and acoustic Doppler velocimeters (ADV)]. The purpose of this report is to describe the equipment and procedures used by the USGS and others for making discharge measurements, and to describe new developments in equipment and procedures. Other traditional methods of measuring streamflow include portable weirs and flumes, and volumetric, float, indirect, and tracer measurements. Relatively new developments include

the use of a moving boat with the ADCP (Mueller and Wagner, 2009), the wading rod mounted ADV, electromagnetic current meters, electronic field notebooks, personal digital assistants (PDAs), and various procedural changes.

The original version of USGS Techniques of Water-Resources Investigations book 3, chapter A8 (TWRI 3–A8), by Buchanan and Somers (1969), was used as an extensive resource in the preparation of this publication because much of the equipment and techniques described by Buchanan and Somers are still applicable to current streamgaging methods. The USGS publications “Measurement and Computation of Streamflow, volumes 1 and 2,” by Rantz and others (1982); “Discharge measurements using a broad-band acoustic Doppler current profiler,” by Simpson (2002); “Quality-assurance plan for discharge measurements using acoustic Doppler current profiler,” by Oberg and others (2005); and “Measuring discharge with acoustic Doppler current profilers from a moving boat,” by Mueller and Wagner (2009), were also used extensively in the preparation of this publication. Numerous parts of this chapter were taken verbatim from Buchanan and Somers (1969), Rantz (1982), Simpson (2002), Oberg and others (2005), and Mueller and Wagner (2009), and even though some of these parts are not specifically denoted, credit is hereby given to these authors.

Definition of Streamflow

Streamflow, or discharge, is defined as the volumetric rate of flow of water (volume per unit time) in an open channel, including any sediment or other solids that may be dissolved or mixed with it that adhere to the Newtonian physics of open-channel hydraulics of water. The definition of streamflow in this chapter does not include non-Newtonian flow events such as debris flows and lahars (an avalanche of volcanic mud and water down the slopes of a volcano). Streamflow in the USGS is usually expressed in English dimensions of cubic feet per second (ft^3/s). Other common units are million gallons per day (Mgal/d) and acre-feet per day (ac-ft/d). Streamflow cannot be measured directly but must be computed from variables that can be measured directly, such as stream width, stream depth, and streamflow velocity. Even though streamflow is computed from measurements of other variables, the term “streamflow measurement” or “discharge measurement” is generally applied to the final result of the calculations.

Discharge Measurements at Gaging Stations

Procedures for making most types of current-meter [mechanical meters, electromagnetic meters, ADV meters, acoustic digital current meters (ADCs), and so forth], moving-boat ADCP, and ADCP midsection measurements are described in the following sections. For much of the discussion of moving-boat ADCP, the reader is referenced to Mueller and Wagoner (2009). The chapter includes discussions on the selection of a measuring section, laying out the stationing for subsection verticals, width measurements, depth measurements, velocity measurements, direction of flow measurements, and recording of field notes. Additional details that pertain to instrumentation and specific types of measurements, such as wading, cableway, bridge, boat, and ice, are described in subsequent sections. Special procedures such as networks of current meters, measurement of deep, swift streams, and measurements during rapidly changing stage are also described.

Velocity-Area Method

The most practical method of measuring the discharge of a stream is the velocity-area method. Discharge is computed as the product of the area and velocity. The measurement is made by subdividing a stream cross section into segments (sometimes referred to as partial areas, sections, subareas, verticals, stations, profiles, panels, or ensembles), and by measuring the depth and velocity in a vertical within each segment. The total discharge is the summation of the products of the partial areas of the stream cross section and their respective average velocities. This computation is classically expressed by the equation

$$Q = \sum_{i=1}^n a_i v_i \quad (1)$$

where Q total discharge, in cubic feet per second,
 a_i cross-section area, in square feet, for the i th segment of the n segments into which the cross section is divided, and
 v_i the corresponding mean velocity, in feet per second of the flow normal to the i th segment, or vertical.

Midsection Method

The current-meter midsection method of making a current-meter discharge measurement is used by the USGS and others. The method assumes that the mean velocity in each vertical represents the mean velocity in a partial rectangular area (segment). The mean velocity in each vertical is determined by measuring the velocity at one or more selected points in that vertical, as described in a later section of this chapter. The cross-section area for a segment extends laterally from half the distance from the preceding vertical to half

the distance to the next vertical, and vertically, from the water surface to the sounded depth as shown in figure 1.

The cross section in figure 1 is defined by depths at locations 1, 2, 3, 4, . . . , n . At each location, the velocities are sampled by current meter to obtain the mean of the vertical distribution of velocity. The partial discharge is now computed for any partial section (segment) at location i as

$$q_i = v_i \left[\frac{(b_i - b_{(i-1)})}{2} + \frac{(b_{(i+1)} - b_i)}{2} \right] d_i, \text{ or} \quad (2)$$

$$= v_i \left[\frac{b_{(i+1)} - b_{(i-1)}}{2} \right] d_i, \quad (3)$$

where q_i discharge through partial section i ,
 v_i mean velocity at location i ,
 b_i distance from initial point to location i ,
 $b_{(i-1)}$ distance from initial point to preceding location,
 $b_{(i+1)}$ distance from initial point to next location, and
 d_i depth of water at location i .

Thus, for example, the discharge through partial section 4 (heavily outlined in figure 1) is

$$q_4 = v_4 \left[\frac{b_5 - b_3}{2} \right] d_4. \quad (4)$$

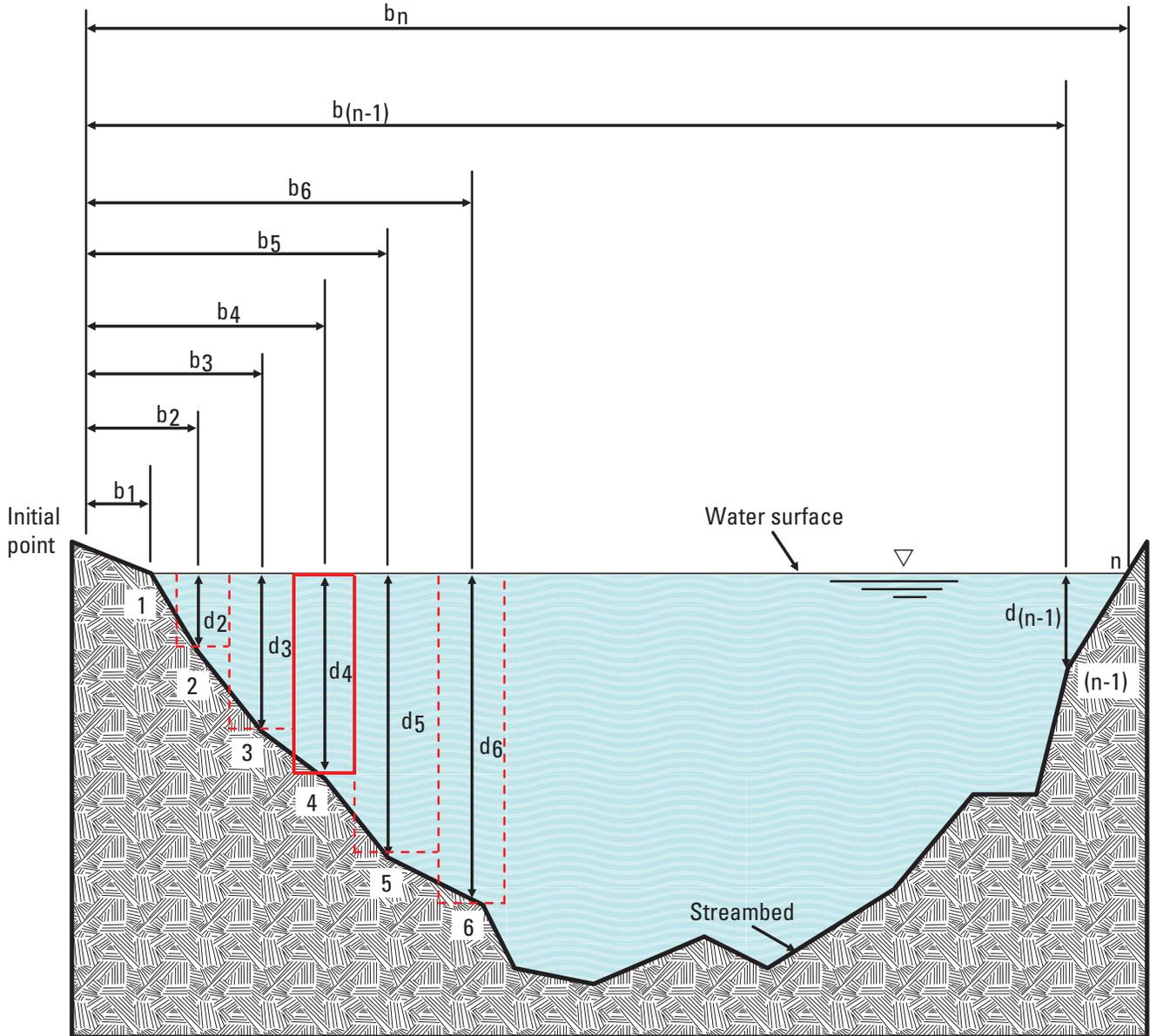
The procedure is similar when i is at an end section. The “preceding location” at the beginning of the cross section is considered coincident with location 1; the “next location” at the end of the cross section is considered coincident with location n . Thus,

$$q_1 = v_1 \left[\frac{b_2 - b_1}{2} \right] d_1, \text{ and} \quad (5)$$

$$q_n = v_n \left[\frac{b_n - b_{(n-1)}}{2} \right] d_n. \quad (6)$$

For the example shown in figure 1, q_1 is zero because the depth at observation point 1 is zero. However, when the cross-section boundary is a vertical line at the edge of the water as at location n , the depth is not zero and velocity at the end section may or may not be zero. Equations 5 and 6 are used whenever there is water only on one side of an observation point, such as at the edge of the stream, piers, abutments, and islands. It usually is necessary to estimate the velocity at an end section because it normally is impossible to measure the velocity accurately with the current meter close to a boundary. There also is the possibility of damage to the equipment if the flow is turbulent. The estimated velocity is usually made as a percentage of the adjacent section.

The summation of the discharges for all the partial sections is the total discharge of the stream. An example of the measurement notes is shown in figure 2A. In the hydraulic properties reported, the summation of discharges from an ADV discharge



EXPLANATION

- 1, 2, 3,..... n Observation points
- $b_1, b_2, b_3, \dots, b_n$ Distance, in feet, from the initial point to the observation point
- $d_1, d_2, d_3, \dots, d_n$ Depth of water, in feet, at the observation point
- Boundary of partial sections; one heavily outlined discussed in text

Figure 1. Definition sketch of the current-meter *midsection* method of computing cross-section area for discharge measurements.

measurement (fig. 2B) is similar to that of a current meter; however, it is designed to report the properties inherent to the ADV software and signal processing necessary to compute discharge using acoustic Doppler technology. A program written by staff in the USGS Maine Water Science Center entitled Surface Water Measurements and Inspections (SWAMI) has become common in use in the USGS with a PDA, and may be used to

record discharge measurements, inspections, differential level surveys, and other field measurements (fig. 2C).

Included here for convenience is a typical, well-documented ADCP discharge measurement (fig. 2D). This measurement serves as an example of how an ADCP measurement note should be kept in the field. Further discussion of ADCP measurements can be found in subsequent sections of this chapter.

9-275-x	01/24/2007	U.S. DEPARTMENT OF THE INTERIOR U.S. Geological Survey		Meas. No.	625
Station Number	03329700	ADY Discharge Measurement Notes		Comp. by	SEM
Station Name	Deer Creek nr Delphi, IN	ADY Discharge Measurement Notes		Checked by	RSG
Date	8/18/2009	Party	SEMORLOCK	Discharge	59.8
Width	63	Area	51.6	Velocity	1.16
Method	0.6	# Sections	30	SNR	32
Diagnostic Test File	P156.080509.bmc	Std Velocity Profile	Measured Water Temp	Gage Height	2.08
Raw Data File	03329700.WAD	or N or Uncertain	24.5°F / C at 1100	Gage Height Change	
Manufacturer	Sontek	ADV Sync'd to WT	ADV Water Temp	hrs.	0.52
Model	FlowTracker P156A	at 1120	or N	73.1	°F / C at 1140
Serial No.	ETG STAFF	Firmware	3.3	Software	2.20
Gage Readings					
Time	1052	DCP	Inside	Outside	Rating number
	1123		2.09	2.08	2.08
	1155				Percent from rating
	1207				Indicated shift
Weighted MGH					
GH corrections					
Correct MGH					
Wading	Steady and Even	at			
Measurement rated	excellent (2%) (good (5%) fair (8%), poor (>8%)	based on following conditions			
Flow	Steady and Even				
Cross section	Sandy gravel and gravel, fairly even				
Control	Sandy gravel and cobbles 100' ds clear				
Gage operating	Record removed	or N	File name	03329700.109	
Battery voltage	12.8 V	Inlets	cleaned/purged	Yes	
Bubble-gage psi	Tank	Line	Bubble rate	na	/ min
Extreme-GH indicators:	Max	2.45	Min	1.87	CSG Checked
HWM on stick	no	Ref elev.	4.32	HWM elevation	na
GH of zero flow = GH	2.08	- depth at control	1.20	= .88 ft.	Rated Fair
Remarks					
Sheet No.	1	of	2	sheets	

Discharge Measurement Summary

Date Generated: Tue Nov 17 2009

File Information		Site Details	
File Name	03329700.WAD	Site Name	
Start Date and Time	2009/08/18 11:23:50	Operator(s)	HTM
System Information		Units (English Units)	
Sensor Type	FlowTracker	Distance	ft
Serial #	P156A	Velocity	ft/s
CPU Firmware Version	3.3	Area	ft^2
Software Ver	2.20	Discharge	cfs
Summary		# Stations	30
Averaging Int.	LEW	Total Width	63.000
Start Edge	32.0 dB	Total Area	51.550
Mean SNR	73.12 °F	Mean Depth	0.818
Mean Temp	Mid-Section	Mean Velocity	1.1593
Disch. Equation		Total Discharge	59.7613

Discharge Uncertainty			
Category	ISO	Stats	
Accuracy	1.0%	1.0%	
Depth	0.2%	1.0%	
Velocity	0.6%	3.1%	
Width	0.1%	0.1%	
Method		1.5%	
# Stations		1.7%	
Overall		2.6%	3.4%

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	11:23	4.00	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	11:23	4.00	0.6	0.402	0.6	0.160	0.2966	1.00	0.2966	1.200	0.3558	0.6
2	11:25	6.00	0.6	0.500	0.6	0.200	0.4426	1.00	0.4426	1.000	0.4426	0.7
3	11:26	8.00	0.6	0.600	0.6	0.240	0.6266	1.00	0.6266	1.200	0.7521	1.3
4	11:27	10.00	0.6	0.800	0.6	0.320	0.7802	1.00	0.7802	1.600	1.2461	2.1
5	11:28	12.00	0.6	1.100	0.6	0.440	0.9803	1.00	0.9803	2.200	2.1568	3.6
6	11:29	14.00	0.6	1.300	0.6	0.520	0.8986	1.00	0.8986	2.600	2.3362	3.9
7	11:30	16.00	0.6	1.300	0.6	0.520	0.9829	1.00	0.9829	2.600	2.5554	4.3
8	11:32	18.00	0.6	1.300	0.6	0.520	1.1299	1.00	1.1299	2.600	2.9375	4.9
9	11:33	20.00	0.6	1.300	0.6	0.520	1.2979	1.00	1.2979	2.600	3.3742	5.6
10	11:34	22.00	0.6	1.100	0.6	0.440	0.9744	1.00	0.9744	2.200	2.1438	3.6
11	11:36	24.00	0.6	1.100	0.6	0.440	1.4452	1.00	1.4452	2.200	3.1797	5.3
12	11:37	26.00	0.6	1.200	0.6	0.480	0.9862	1.00	0.9862	2.400	2.3672	4.0
13	11:38	28.00	0.6	1.200	0.6	0.480	1.0472	1.00	1.0472	2.400	2.5137	4.2
14	11:39	30.00	0.6	1.000	0.6	0.400	0.9636	1.00	0.9636	2.000	1.9222	3.2
15	11:40	32.00	0.6	1.000	0.6	0.400	0.9551	1.00	0.9551	2.000	1.9101	3.2
16	11:41	34.00	0.6	1.000	0.6	0.400	1.5469	1.00	1.5469	2.000	3.0938	5.2
17	11:42	36.00	0.6	1.000	0.6	0.400	1.4954	1.00	1.4954	2.000	2.9908	5.0
18	11:44	38.00	0.6	1.000	0.6	0.400	1.4741	1.00	1.4741	2.000	2.9482	4.9
19	11:45	40.00	0.6	0.900	0.6	0.360	1.5633	1.00	1.5633	1.800	2.8138	4.7
20	11:46	42.00	0.6	0.900	0.6	0.360	1.3133	1.00	1.3133	1.800	2.3638	4.0
21	11:47	44.00	0.6	0.800	0.6	0.320	1.6240	1.00	1.6240	1.600	2.5980	4.3
22	11:48	46.00	0.6	0.800	0.6	0.320	1.2562	1.00	1.2562	1.600	2.0096	3.4
23	11:49	48.00	0.6	0.700	0.6	0.280	1.6437	1.00	1.6437	1.400	2.3016	3.9
24	11:51	50.00	0.6	0.700	0.6	0.280	1.4249	1.00	1.4249	1.400	1.9952	3.3
25	11:52	52.00	0.6	0.600	0.6	0.240	1.2969	1.00	1.2969	1.200	1.5565	2.6
26	11:53	54.00	0.6	0.600	0.6	0.240	1.4646	1.00	1.4646	1.200	1.7577	2.9
27	11:54	56.00	0.6	0.500	0.6	0.200	1.4452	1.00	1.4452	1.000	1.4452	2.4
28	11:55	58.00	0.6	0.500	0.6	0.200	0.9639	1.00	0.9639	1.750	1.6868	2.8
29	11:55	63.00	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

6 Discharge Measurements at Gaging Stations

01031500 - Site Visit Summary - 2009-05-20

SWAMI ver. 0.1.5

Site Visit Summary																
Site Number: 01031500		Site Name: Piscataquis River near Dover-Foxcroft, Maine														
Date: 2009-05-20		Start Time: 09:13:07		End Time: 10:48:46												
Party: LEF		Weather: Sunny														
Comment:																
Discharge Measurement																
Meas #: 872		Meas Flow: 440 cfs		Time: 10:05:48												
Stage: 3.02 ft		Stage Change: -01 ft		Change Duration: 1.4 hrs.												
Qm Rated: Fair (8%)		Base Flow: Unspecified														
Comment: Rated fair due to boulders encountered during QM.// This was a good/fair QM.																
Channel 0 Summary																
Name: Main		Meas Flow: 440.013 cfs ()		Qm Type: Wading												
Qm Method: Midsection		Condition: firm, uneven, cobbles-boulders		Vel Method: Price AA												
Horiz Flow: Even		Vel Desc: Steady		Sect Loc.: Downstream 600ft. to gage												
Start Point: Left edge of water		Mtr Type: Price AA		Mtr S/N: ME_P450												
Mtr Susp: Top-setting wading rod		Mtr Insp B4: true		Mtr Insp Aff: true												
Dist to Mtr:		Wt Used:		Summary Only: false												
Total Area: 272		Total Width: 133		Mean Vel: 1.62												
Stn. #	Time	Flow/bat	Cov%	Dist (ft)	Width (ft)	TotDepth (ft)	Ice (ft)	bDepth (ft)	Velocity Observations			Adj Vel	Area (sq ft)	Discharge (cfs)	Com	
%Depth	Vel	Time	Adj Vel													
1	09:22:56	EstN	75	3.0	0.5	.91			6	14	41	0.771	0.578	0.46	0.266	--
2	09:25:36		95	4.0	1.75	.80			6	19	41	1.04	0.756	1.4	1.058	
3	09:28:31		1.00	6.5	2	1.20			6	25	40	1.4	1.4	3.63	2.496	
4	09:31:07		1.00	8.0	2.75	1.32			6	25	40	1.4	1.4	6.52	9.128	--
5	09:33:27		1.00	12	4	1.63			6	23	41	1.25	1.25	7.4	9.25	
6	09:35:09		1.00	16	4	1.85			6	27	41	1.47	1.47	6.6	9.702	--
7	09:37:05		1.00	20	4	1.65			2	33	40	1.84	1.575	8.76	13.797	
8	09:39:54								8	24	41	1.31				
9	09:43:15		1.00	26	3	3.06			2	35	40	2.11	1.78	9.18	16.340	
									8	26	40	1.45				
10	09:46:30		1.00	30	3	3.14			2	35	40	2.11	1.63	9.42	15.355	
									8	21	41	1.15				
11	09:49:36		1.00	32	3	3.28			2	37	40	2.06	1.755	9.84	17.269	
									8	26	40	1.45				
12	09:52:34		1.00	36	3	3.42			2	43	41	2.33	1.92	10.26	19.699	
									8	27	40	1.51				
13	09:55:30		1.00	38	3	3.32			2	42	40	2.33	1.975	9.96	19.671	
									8	29	40	1.62				
14	09:58:34		1.00	42	3	3.24			2	46	40	2.55	2.17	9.72	21.092	
									8	33	41	1.79				
15	10:01:18		1.00	44	3	3.02			2	45	40	2.50	2.195	9.06	19.887	
									8	34	40	1.89				
16	10:04:29		1.00	48	3	3.05			2	49	41	2.65	2.3	9.15	21.045	
									8	35	40	1.95				
17	10:07:32		1.00	50	3	3.20			2	51	40	2.83	2.39	9.6	22.944	
									8	35	40	1.95				
18	10:10:30		1.00	54	3	3.12			2	49	40	2.72	2.39	9.36	22.370	
									8	37	40	2.06				
19	10:13:59		1.00	56	3	2.65			2	48	40	2.66	2.26	7.95	18.126	
									8	35	41	1.90				
20	10:17:20		1.00	60	3	2.86			2	46	40	2.55	2.09	8.58	17.932	
									8	30	41	1.63				
21	10:21:21		1.00	62	3	2.91			2	48	40	2.55	2.085	8.73	18.202	
									8	29	40	1.62				
22	10:24:08		1.00	66	4	2.62			2	44	40	2.44	2.14	10.48	22.427	
									8	33	40	1.84				
23	10:26:11		1.00	70	4	2.46			6	38	40	2.11	2.11	9.84	20.762	
24	10:27:43		1.00	74	4	2.42			6	31	42	1.65	1.65	9.65	15.972	
25	10:29:32		1.00	78	4	1.82			6	30	41	1.63	1.63	7.28	11.866	
26	10:31:20		1.00	82	5	1.84			6	22	44	1.12	1.12	9.2	10.304	
27	10:33:20		1.00	86	6	1.72			6	25	40	1.4	1.4	10.32	14.448	
28	10:35:16		1.00	94	6	1.58			6	22	41	1.2	1.2	9.45	11.376	
29	10:36:50		1.00	100	6	1.50			6	19	40	1.07	1.07	9	9.63	
30	10:38:22		1.00	106	6	1.32			6	18	40	1.01	1.01	7.92	7.988	
31	10:40:12		1.00	112	6	1.18			6	15	41	0.824	0.824	7.08	5.834	--
32	10:45:50		1.00	118	7	1.02			6	8	42	0.438	0.438	7.14	5.127	--
33	10:45:26		1.00	126	5	1.58			6	8	45	0.41	0.41	7.9	3.239	--
34	10:47:38		1.00	128	5	1.73			6	5	44	0.268	0.268	8.65	2.318	--
35	10:48:40		1.00	136	4	0			6	0	40	0	0	0	0	--
Midsection Comments																
Stn #	Comment															
1	LEW															
5	Behind rock															
7	Top of rock															
32	Left edge of sand bar.															
33	Right edge of sand bar.															
35	REW															

C

Acoustic Profiler Discharge Measurement Notes							Filename Prefix: foxmon_ds1200_
Left Bank:	<input checked="" type="radio"/> Sloping <input type="radio"/> Vertical <input type="radio"/> Other: _____			Right Bank:	<input checked="" type="radio"/> Sloping <input type="radio"/> Vertical <input type="radio"/> Other: _____		
Transect No.	Starting			Ending		Total Discharge	Notes
	Bank	Time	Distance	Distance	Time		
0	L R						Moving bed test in center of channel
1	L <input checked="" type="radio"/> R	1249	16	69	1255	1,321	Simultaneous comparison discharge measurements
2	<input checked="" type="radio"/> L R	1256	69	16	1301	1,358	upstream of dam
3	L <input checked="" type="radio"/> R	1301	69				Transect aborted due to debris in river
4	L <input checked="" type="radio"/> R	1303	69	16	1308	1,327	
5	<input checked="" type="radio"/> L R	1309	16	69	1315	1,356	
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
Notes All times are in CST. Measurement was made using a temporary rope-and-pulley cableway. Edge distances were measured with laser rangefinder by marking the start and ending positions on the rope and measuring the distance from edge of water to the center of the tethered boat.							

9-275-4	7/19/08	U.S. DEPARTMENT OF THE INTERIOR U.S. Geological Survey		Meas. No. 57
Station Number	ADCP Discharge Measurement Notes			Processed by BILL
05551540	Fox River at Montgomery, IL			Checked by KAO
Station Name				
Date	July 6, 2004	Party	B.L. Loving, S.E. Anderson	
Width	Area / Rated Area	Velocity	Index Vel.	Gage Height
235	707	1.90		11.74
Gage Height Change	Meas. plots	From rating	Sluff	ADCP Sync'd to WT
0.00 in 0.4 hrs	4.4% diff	No.: 11	0.0	<input checked="" type="radio"/> at 1207 or N
ADCP Mfr / Model / Frequency	Serial No.	Firmware	Software	
RDI Rio Grande 1200	1636	10.14	WinRiver 10.06	
Boat/Motors Used	GPS Used	ADCP Depth	Diag. Test / Errors?	
OceanScience Tethered	Trimble AgGPS	0.27 ft	<input checked="" type="checkbox"/> Y or <input checked="" type="checkbox"/> N	Moving Bed?
Compass Calib. & Total Error	Mag. Var	MagVar Method		
<input checked="" type="radio"/> or N	0.8	-2.4	On-site (Model) Previous	Y or <input checked="" type="checkbox"/> N
Meas. Water Temp	ADCP Water Temp	Weather / Air Temp	Wind Speed / Dir.	
26.5 °F / <input checked="" type="radio"/> at 1210	26.5 °F / <input checked="" type="radio"/> at 1210	Sunny/clear 85°F / C	Southerly @ 5-10 mph	
Gage Readings				
Time	ETG	CR10	Inside	Outside
1100	11.74	11.70	11.70	Max Water Depth 10 ft
1230		11.70	+0.05	Max Water Speed 2.5 ft/s
1249 (S)		11.70	11.70	Max Boat Speed 1 ft/s
1300		11.70	11.70	Water Mode 12
1315 (F)		11.70	11.70	Bottom Mode 5
				Streambed material
				Gravel
1400	11.74	11.70	11.70	Salinity
Weighted MGH	11.74		+0.05	ppt at
GH corrections				Checkbar found 22.41
Correct MGH	11.74			Checkbar changed to:
				--- at ---
Wading cable, ace, boat, upstr., downstr., side bridge	1500	<input checked="" type="radio"/> mi. upstr. (downstr.) of gage		
Measurement rated:	excellent (2%) (good (5%) fair (8%), poor (<8%))	based on following conditions		
Flow	Steady & uniform. Flow at edges appears to be moving in DS direction			
Cross section:	Sand and Gravel with some mud			
Control:	Dam is clear of debris			
Gage operating:	<input checked="" type="radio"/> or N	Record removed:	Y or <input checked="" type="radio"/> N	Filename: Telephone telemetry
Battery voltage	12.5 V	Inlets/Onifice cleaned/purged:	No	
Bubble-gage psi:	Tank ---	Line ---	0	--- / min
Extreme-GH indicators:	Max ---	Min ---	CSG Checked	<input checked="" type="radio"/> or N
HWM on stick	None	Ref elev.	12.65	HWM elevation None
GH of zero flow = GH	---	- depth at control	---	= --- ft. Rate= 10.48
				Sheet No. 1 of 1 sheets

8 Discharge Measurements at Gaging Stations

The mean-section method used by the USGS prior to 1950 differs from the midsection method in computation procedure. Partial discharges are computed for partial sections between successive verticals. The velocities and depths at successive verticals are each averaged, and each partial section extends laterally from one vertical to the next. Discharge is the product of the average of two mean velocities, the average of two depths, and the distance between verticals. A study by Young (1950) concluded that the midsection method is simpler to compute and is a slightly more accurate procedure than the mean-section method.

Site Selection

The first and most critical step in making a midsection current-meter or ADV measurement, or an ADCP measurement is to select a measurement cross section of desirable qualities. If the stream cannot be waded, nor high-water measurements made from a bridge, moving or tethered boat, or cableway, the hydrographer may have little or no choice in selecting a measurement cross section. If the stream can be waded or the measurement can be made from a boat, the hydrographer should look for a cross section with the following characteristics:

- There is a reasonably straight channel with streamlines parallel to each other; a stable streambed free of large rocks, weeds, and obstructions that would create eddies, slack water, and turbulence; and desirable measurement sections that are roughly parabolic, trapezoidal, or rectangular. These conditions are obviously not always possible, but remember that most current meters are rated in a still water tank by towing them through the tank at a known speed. With that in mind, these are conditions a hydrographer should seek in the field: a smooth, mirror-like water surface with steady, uniform, nonvarying flow conditions in the stream reach where the discharge measurement will be taken.
- The velocities are, for the most part, greater than 0.5 ft/s, and depths that are greater than about 0.5 ft. These conditions are not always possible to find in the field.
- The measurement section is relatively close to the gaging station control to avoid the effect of tributary and (or) intervening drainage area inflows between the measurement section and the control, and to avoid the effect of channel storage between the measurement section and the control during periods of changing stage.

It is usually not possible to satisfy all of these conditions. Select the best possible reach using these criteria and then select a cross section. For a further discussion regarding site selection when using a mechanical or other point-velocity current meter refer to Rantz and others (1982).

For convenience, special site-selection considerations for an ADCP discharge measurement are presented as follows, and further discussion of ADCP methods and instruments is presented in subsequent sections of this chapter:

- The minimum depth near the left and right edges of water at the measurement site should allow for the measurement of velocity in two or more depth cells while being close enough to minimize the estimated edge discharges.
- Make sure velocities are, for the most part, greater than 0.5 ft/s, and depths are greater than the minimum depth required by the ADCP. Although measurements can be made in low velocities, keep boat speeds extremely slow (if possible, less than or equal to the average water velocity), which requires special techniques for boat control (Simpson, 2002).
- Avoid measurement sections having local magnetic fields, especially if a moving bed is present and a Global Positioning System with differential corrections (DGPS) or the Loop Method (Mueller and Wagoner, 2006) is used. For example, during measuring, avoid overhead truss bridges, low steel-beam spans, power lines, and other sources of magnetic fields. Just as with ADCP mounts and boats, the presence of ferrous metals will result in ADCP compass errors.
- If possible, avoid asymmetric channel geometries (for example, deep on one side and shallow on the other; Simpson, 2002) and avoid cross sections with abrupt changes in channel-bottom slope. The streambed cross section should be as uniform as possible and free from debris and vegetation or plant growth.
- When using DGPS with an ADCP, avoid cross-section locations where multipath interference, such as riparian vegetation (low-hanging trees and large bushes on river or stream banks), buildings at or near the river banks, bridges, and other flow-control structures, could impede or block signals from GPS satellites.

It is usually not possible to attain all of these conditions, but site selection cannot be understated as a critical part of a discharge measurement. Select the best possible reach using these criteria and then select a cross section. For more discussion regarding site selection when using an ADCP, refer to Mueller and Wagner (2009).

Layout and Stationing of Partial Sections and Verticals in a Midsection Current-Meter Discharge Measurement

After the cross section has been selected, determine the width of the stream. For a mechanical current-meter or other point-velocity measurement, string a tag line or measuring tape for measurements made by wading, from a boat, from ice cover, or from an unmarked bridge. Except for bridges, string the line

at right angles to the direction of flow to avoid horizontal angles in the cross section. For cableway or bridge measurements, use the graduations painted on the cable or bridge rail. Next, determine the spacing of the verticals, generally using about 25 to 30 partial sections. With a smooth cross section and even velocity distribution, fewer partial sections may be used. Space the partial sections so that no partial section has more than 10 percent of the total discharge in it. The ideal measurement is one in which no partial section has more than 5 percent of the total discharge in it; this can be challenging when only 25 partial sections are used. For example, the discharge measurement shown in figure 2A had 6.5 percent of the total discharge in the partial section with the greatest discharge. Equal widths of partial sections across the entire cross section are not recommended unless the discharge is evenly distributed. Lessen the width of the partial sections as depths and velocities become greater. Usually an approximate or expected total discharge can be obtained from the stage-discharge curve. Space the verticals so the discharge in each partial section is about 5 percent of the expected total discharge from the rating curve. When using an electronic field notebook [such as the JBS Instruments Aquacalc Pro Discharge Measurement Computer (Aquacalc), a PDA with the Hydrological Services Current Meter Counter signal processor (CMCsp), or the SonTek FlowTracker], the expected total discharge can be entered prior to starting the discharge measurement. During the measurement, a warning message will be displayed if a partial discharge exceeds 10 percent of the expected total discharge. When using an ADV or other acoustic point-velocity instrument, make sure the instrument is appropriately aligned and plumbed to the tag line because slight variations in the alignment of the instrument can result in large errors in the measurement of point velocity. See further discussion of the use of acoustic point-velocity instruments in this chapter.

For a standard mechanical current-meter discharge measurement, the usual procedure, after selecting and laying out the section, is to measure and record at each vertical (1) the distance from the initial point, (2) the depth, (3) the meter position, (4) the number of revolutions, (5) the time interval, and (6) the horizontal angle of flow. The starting point can be either bank. The edge of water, which may have a depth of zero, is considered to be the first vertical. The hydrographer should move to each of the verticals in succession and repeat the procedure until the measurement is completed at the opposite bank.

Measurement of Width

The first measurement made in a discharge measurement is usually the determination of horizontal stationing (width) in the cross section being measured. Width needs to be measured using the proper equipment and procedures that apply to the type of measurement being made (that is, wading, bridge, cableway, boat, or ice). Details of measuring width using a variety of equipment, and under different flow conditions, are described in subsequent sections of this chapter.

The horizontal distance to any vertical in a cross section is measured from an initial point on the bank. Cableways and bridges used regularly for making discharge measurements are commonly marked at 2-, 5-, 10-, and (or) 20-ft intervals by paint marks. Distance between markings is interpolated, or measured with a rule or pocket tape. Steel or Kevlar tag lines and metallic tapes are used for measurements made by wading, from boats, or from unmarked bridges. For wide streams of about 2,500 ft or more, where conventional measuring methods cannot be used, surveying methods and Global Positioning Systems (GPS) can be used.

Tapes and Tag Lines

Tag lines used for wading measurements are usually made of either galvanized steel aircraft cord with solder beads at measured intervals, or Kevlar, which is marked with black ink and waxed to resist abrasion. A Kevlar tag line consists of a Kevlar core with a nylon jacket.

The standard arrangement of solder beads on steel tag lines is shown in table 1. The standard markings for Kevlar tag lines is one mark every 2 ft, two marks every 10 ft, and three marks every 100 ft. The standard lengths of tag lines are 300, 400, and 500 ft, but other sizes are available.

Four types of tag-line reels typically used for the steel tag lines are the Lee-Au, Pakron, Columbus type A, and the USGS Stainless Steel Tag line as shown in figure 3. The reel used for the Kevlar tag line is shown in figure 4.

Larger reels, used for boat measurements, are designed to hold up to 3,000 ft of $\frac{1}{8}$ -inch (in.) diameter steel tag line. These reels and boat measurement methods have largely been replaced by the ADCP technology. Two different types of reels still available are as follows:

- A heavy-duty, horizontal-axis reel without a brake, and with a capacity of 5,000 ft of $\frac{1}{8}$ -in. beaded tag line or 3,000 ft of $\frac{3}{16}$ -in. Kevlar boat tag line, as shown in figure 5.
- A vertical-axis reel without a brake (fig. 6), and with a capacity of 1,500 ft of $\frac{1}{8}$ -in diameter steel tag line (800 ft tag lines are standard) or up to 900 ft of $\frac{3}{16}$ -in. Kevlar boat tag-line cable.

Table 1. Standard markings for steel tag lines.

Distance from initial point (zero mark), in feet	Distance between marks, in feet	Number of solder beads, or tags
0 to 50	2	1 (single bead)
50 to 100	5	1
150 to 500	10	1
0 to 50	10	2 (double bead)
50 to 450	100	2
0 to 500	100	3 (triple bead)

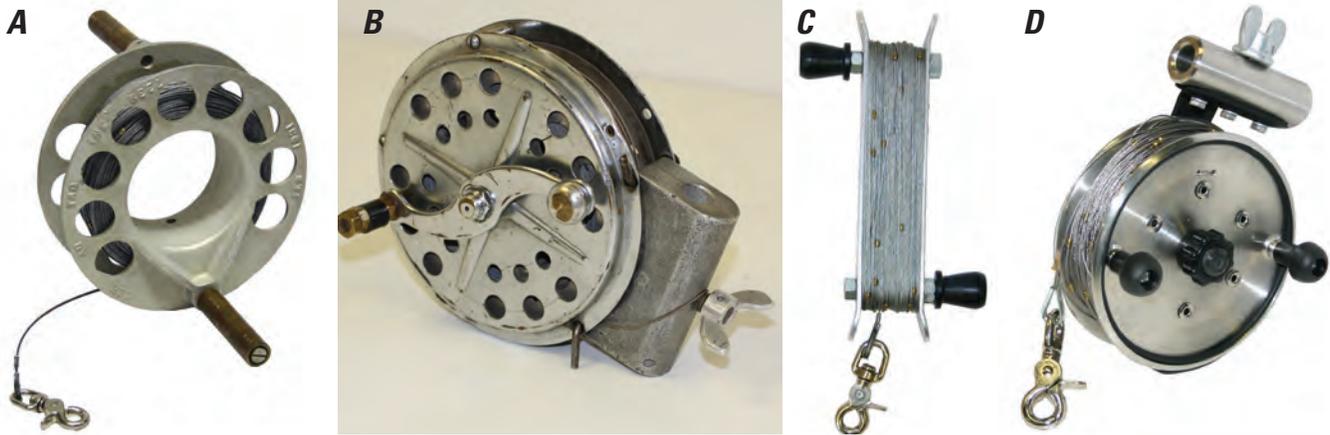


Figure 3. Type-A reels: A, Lee-Au; B, Pakron; C, Columbus; and D, USGS stainless steel tag line.



Figure 4. Kevlar tag-line reel.

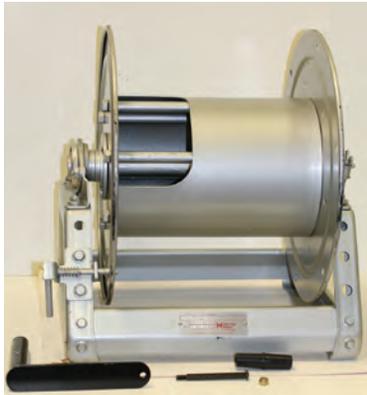


Figure 5. Horizontal-axis boat tag-line reel without a brake.

of a surveying level, as shown in figure 7, or electronic total station instrumentation, as shown in figure 8. The procedure to determine width with a transit is used less frequently, but is described in the section of this chapter on boat measurements.

With the advent of electronic total station surveying instruments and digital surveying levels, a direct reading of the distance can be made from the digital surveying level or from the total station instrument setup point to the boat. One example of a commercially available total station instrument is shown in figure 8. Most of these instruments require a reflector target at the point where a measurement is desired (in this case the boat); however, total station instruments are also available that provide accurate measurements of distance without a reflector target. Accurate distance measurements can be made with total station instruments over distances of 1 mi or more, provided the boat can be seen and not obstructed by intervening objects.



Figure 6. Vertical-axis boat tag-line reel.

Surveying Methods of Width Measurement, Surveying Level, and Electronic Total Station

For wide streams where it is not practical to string a tag line for discharge measurements from a boat, surveying methods can be used to measure stream width and stationing for measurement points. Surveying methods require the use



Figure 7. Surveying level and tripod.



Figure 8. Total station surveying equipment: A, instrument and tripod and B, instrument reflector targets and surveying tape.

Global Positioning System With Differential Corrections

Measurement points can be stationed for wide streams, such as flood plains that may be several miles wide, or large tidal estuaries, with a global positioning system with differential corrections (DGPS) instrument, such as that shown in figure 9, which is a real-time kinematic (RTK) GPS base station with radio transmitter. RTK-GPS and other DGPS instruments utilize

satellite telemetry from an array of satellites, and use radio triangulation to compute positions for any point on the Earth. In order to obtain the accuracy necessary for a discharge measurement, the raw GPS positions must have differential corrections applied on the basis of simultaneous readings at a base station. Most DGPS units contain built-in differential correction receivers that make automatic and instantaneous corrections. Other GPS units may use a separate receiver that attaches to the GPS unit with a cable. In either case, base station data are received by radio signal from nearby ground base stations or via communications satellites from a network of ground stations, such as the Wide Area Augmentation System (WAAS).

A surveying grade DGPS unit with capability of storing and recalling data is preferred. These units may or may not have built-in or attached differential correction receivers. If instantaneous differential corrections are not made, then use correction data obtained after the fact from a separate GPS base station to postprocess coordinate data. Various agencies collect and provide the base station data via the Internet. Coordinate data for the measurement points are downloaded from the GPS unit to a computer for postprocessing. Software is available to make the differential corrections, to compute corrected coordinates of the measurement points, and to automatically compute distances between and to plot a map of the measurement points.



Figure 9. Global positioning system with real-time kinematic (RTK-GPS) base station and radio transmitter.

Accuracy of GPS coordinates will vary depending on the type of GPS unit used and whether or not differential corrections are made. Coordinates without differential corrections can be in error by as much as ± 300 ft because of various errors in the system. Obviously, this is not acceptable for discharge measurements. However, if care is taken in making observations, and then making differential corrections, errors can be reduced to as little as ± 3 ft, and even less in ideal conditions. This method is acceptable for wide flood plains and inaccessible estuaries with open skies and minimal reflective surfaces, which can result in multipath errors.

Measurement of Depth

The second measurement normally made at a vertical is the stream depth. Depth should be measured using the proper equipment and procedures that apply to the type of measurement being made (that is, wading, bridge, cableway, boat, or ice). Details of measuring depth using various equipment and under different flow conditions are described in the following sections of this chapter. The water depth of a stream at a selected vertical can be measured in several ways, depending on the type of measurement being made, the total depth of the stream, and the velocity of the stream. Stream depth is usually measured by use of a wading rod, sounding lines and weights, acoustic Doppler sensor, or another sonic sounder, as described in the following sections of this chapter.

Use of Wading Rod

Use a wading rod for measuring stream depth when depth is shallow enough, or when measuring from a low footbridge or other supportive structure over the stream. Likewise, use the wading rod for measuring from ice cover for shallow depths. Wading rods can even be used from a boat if depths are not too great. The top-setting wading rod can be used for depths up to 4 ft, but greater depths can be measured with 6-, 8-, and 10-ft top-setting wading rods. The round wading rod, which is assembled with 1-ft sections, can be made up into any length, but generally is not used for depths greater than about 10 ft. Velocity of flow is also a consideration because high velocity may not allow for keeping a long wading rod in place.

Wading rods have a small foot on the bottom to allow the rod to be placed firmly on the streambed, and yet not sink into the streambed under most conditions. In sand-bottom streams, or in soft muck, it is sometimes difficult to keep the wading rod from sinking into the streambed as the weight of the rod and meter and the eroding power of the flowing water cause the foot of the wading rod to sink. The hydrographer must use care in these conditions to be sure the measured water depth, as well as the depth of the current-meter placements, are accurately based on the surface of the streambed. In some cases, the wading rod may need to be supported in some manner other than resting on the streambed.

When using a wading rod in streams with moderate-to-high velocity, there will be a velocity-head build-up of water on the wading rod. The stream depth should be based on where the surface of the stream intersects the wading rod, and not on the top of the velocity-head build-up. Wading rods are graduated in tenths-of-a-foot, and stream depths are generally measured or estimated and recorded to the nearest 0.01 ft.

Use of Sounding Lines and Weights

Water depth is measured with sounding lines and weights when the depth is too great to use a wading rod, and when measuring conditions require measuring from a bridge, cableway, or boat. This section will describe the measurement of depth when using sounding reels and handlines. It also discusses the procedures used to correct observed depths when high velocity causes the weight and meter to drift downstream.

Use of Sounding Reels

When using one of the sounding reels described in a subsequent section of this chapter, a counter or dial is used to determine the length of cable that has been dispensed. Depths are measured to the nearest 0.1 ft when using a sounding line and weight.

The size of the sounding weight used in current-meter measurements depends on the maximum depth and velocity in a cross section. A rule of thumb is that the size of the weight in pounds should be greater than the maximum product of velocity and depth in the cross section. If insufficient weight is used, the sounding line will be dragged at an angle downstream. If debris or ice is flowing or if the stream is shallow and swift, a heavier weight can be used than the rule designates. The rule is not rigid but it does provide a starting point for deciding on the size of the weight that is needed. If available, notes can be examined of previous measurements at a site to help determine the size of the weight needed at various stages.

Some sounding reels are equipped with a computing depth indicator, or spiral. To use the computing spiral, the dial pointer must be set at zero when the center of the current-meter rotor is at the water surface. After the sounding weight and meter are lowered until the weight touches the streambed, and the indicated depth should be read. The distance that the meter is mounted above the bottom of the weight should be added. For example, if a 30 C .5 (that is, a 30-pound Columbus weight is being used and the center of the meter cups is 0.5 ft above the bottom of the weight) suspension is used and the dial pointer reads 18.5 ft when the sounding weight touches the streambed, the depth would be 19.0 ft ($18.5 + 0.5$). To move the meter to the 0.8-depth position, merely raise the weight and the meter until the pointer is at the 19-ft mark on the graduated spiral, which will correspond to 15.2 ft on the main dial (0.8×19.0). To set the meter at the 0.2-depth position, raise the weight and meter until the pointer is at 3.8 ft on the main dial (0.2×19.0).

Tags can be placed on the sounding line a known distance above the center of the meter cups as an aid in determining depth. The tags, which are usually streamers of

different-colored binding tape, are fastened to the sounding line by solder beads or by small cable clips. Tags are used for determining depth in two ways; the following is the preferred procedure:

1. Set the tag at the water surface and then set the depth indicator to read the distance of that tag above the center of the meter cups.
2. Continue as if the meter cups themselves have been set at the water surface.
3. When the weight touches the streambed, read the depth indicator and add the distance that the meter is above the bottom of the weight to obtain the total depth.
4. Use the spiral indicator, as described above, for setting the 0.8-depth meter position. If debris or ice is flowing, this method keeps the meter below the water surface and helps to prevent damage to the meter.

This is an alternate method that is sometimes used with handlines and sounding reels: With the sounding weight on the streambed, raise the weight until the first tag below the water surface appears at the surface. If using a reel, determine the distance the weight was raised by subtracting before and after readings of the depth indicator; if using a handline, use a tape or measuring stick. The total stream depth is the sum of (a) the distance the weight was raised to bring the tag to the water surface, (b) the distance the tag is above the center of the meter cups, and (c) the distance from the bottom of the weight to the center of the cups.

Use of a Handline

Although rarely used in the USGS, handlines still provide a viable means of measuring discharge from bridges. When using a handline, unwind enough cable from the handline reel to keep the reel out of water when the sounding weight is on the streambed at the deepest part of the cross section. If the bridge is high enough above the water surface, raise and lower the weight and meter by the rubber-covered cable rather than by the bare cable.

The usual procedure for determining depths is to set the meter cups at the water surface and then lower the sounding weight to the streambed while measuring the amount of line needed to reach the streambed. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is lowered. This measured distance, plus the distance from the bottom of the sounding weight to the meter cups, is the depth of water. When the meter is set for the velocity observation, stand on the rubber-covered cable or tie it to the handrail to hold the meter in place. This arrangement frees the hands to record the data.

Another method of determining depth when using a handline includes the use of tags set at a known distance above the meter. Lower the sounding weight to the streambed, and then raise the weight until one of the tags is at the water surface. Measure along the rubber-covered service cord with a steel or metallic tape or a graduated rod to determine the distance the weight is raised. The total depth of water is then the

summation of (1) the distance the particular tag is above the meter cups, (2) the measured distance the meter and weight was raised, and (3) the distance from the bottom of the weight to the meter cups.

Depth Corrections for Downstream Drift of Current Meter and Weight

Where it is possible to sound but the weight and meter drift downstream, the depths measured by the usual methods are too great. Figure 10 graphically illustrates this condition. The correction for this error has two parts, the air correction and the wet-line correction. The air correction is shown in figure 10 as the distance cd . The wet-line correction in figure 10 is shown as the difference between the wet-line depth de and the vertical depth dg .

As shown in figure 10, the air correction depends on the vertical angle P and the distance ab . The correction is computed as follows:

$$\begin{aligned}\cos P &= \frac{ab}{ad} = \frac{ab}{ac + cd} = \frac{ab}{ab + cd} \Rightarrow \\ ab + cd &= \frac{ab}{\cos P} \Rightarrow \\ cd &= \frac{ab}{\cos P} - ab = ab \left[\frac{1}{\cos P} - 1 \right]\end{aligned}\quad (7)$$

where $ab = ac$

The air correction for even-numbered angles between 4 degrees and 36 degrees and vertical lengths between 10 and 100 ft is shown in table 2. The correction is applied to the nearest tenth of a foot; hundredths are given to aid in interpolation.

Use of an air correction table may be nearly eliminated by using tags at selected intervals on the sounding line and using the tags to refer to the water surface. This practice is almost equivalent to moving the reel to a position just above the water surface.

The correction for excess length of line below the water surface is obtained by using an elementary principle of mechanics. If a known horizontal force is applied to a weight suspended on a cord, the cord takes a position of rest at some angle with the vertical. The tangent of the vertical angle of the cord is equal to the horizontal force divided by the vertical force owing to the weight. If several additional horizontal and vertical forces are applied to the cord, the tangent of the angle in the cord above any point is equal to a summation of the horizontal forces below that point, divided by the summation of the vertical forces below the point.

The distribution of total horizontal drag on the sounding line is in accordance with the variation of velocity with depth. The excess in length of the curved line over the vertical depth is the sum of the products of each tenth of depth and the function $[(1/\cos P) - 1]$ of the corresponding angles. The function is derived for each tenth of depth by means of the tangent relation of the forces acting below any point.

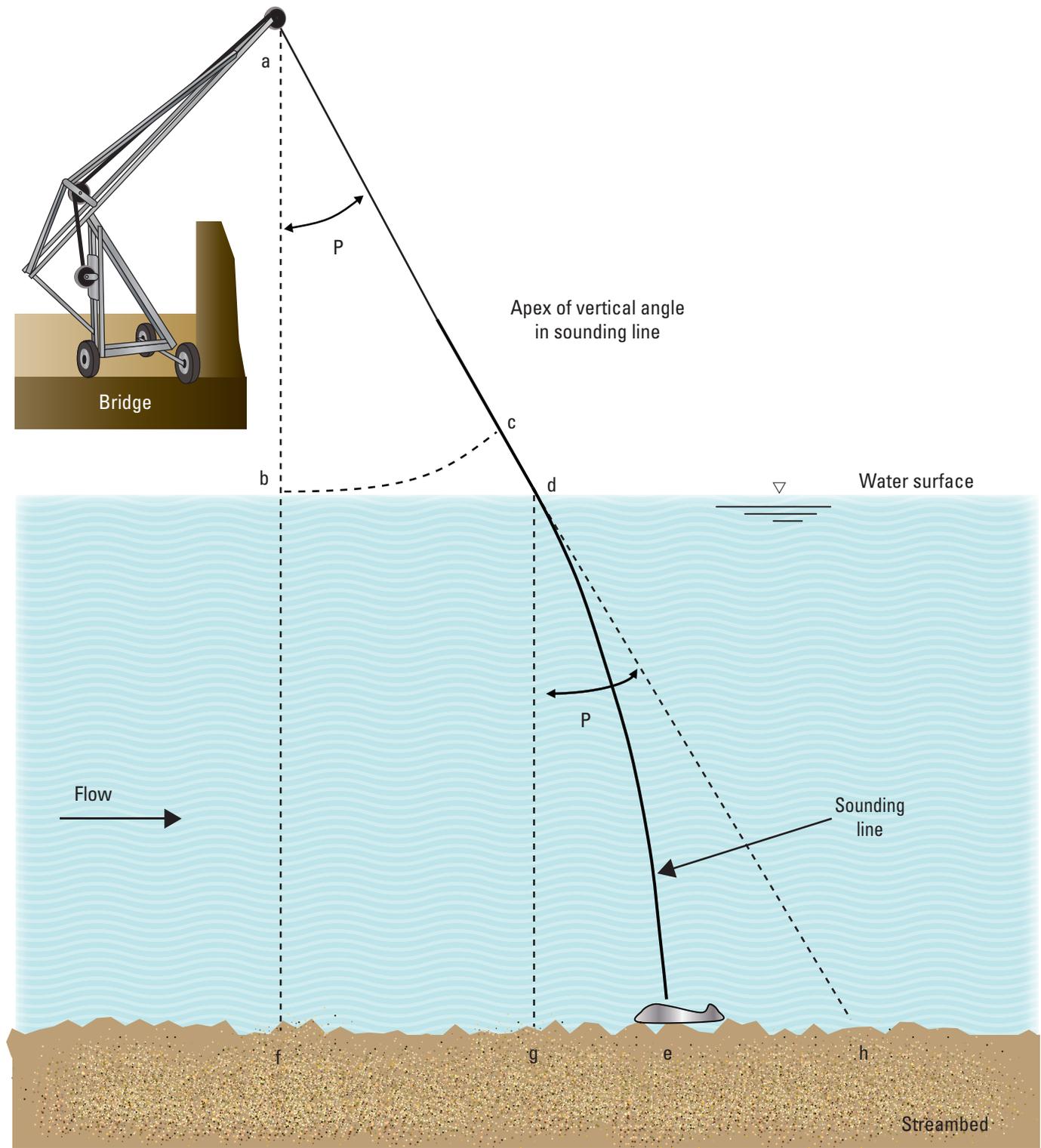


Figure 10. Position of sounding weight and line in deep, swift water.

The wet-line correction for even-numbered angles between 4 degrees and 36 degrees and wet-line depths between 10 and 100 ft is shown in table 3. The correction is applied to the nearest tenth of a foot. The wet-line correction cannot be determined until the air correction has been deducted from the observed depth.

The following assumptions were used in deriving the wet-line correction table:

1. The weight will go to the bottom despite the force of the current.
2. The sounding is made when the weight is at the bottom but entirely supported by the line.
3. Drag on the streamlined weight in the sounding position is neglected.
4. The air-line/wet-line table is generic and can be used for any size sounding weight or line, provided they are designed to offer little resistance to the current.

Wet-line corrections can also be computed with the equation below. This polynomial equation was derived by Kenneth L. Wahl (U.S. Geological Survey [ret.], Regional Surface Water Specialist, written commun., 2000) from the data in table 3, and reproduces the table values to within a few hundredths of a foot. It can be used in a field computer to quickly and easily compute wet-line corrections. With additional programming, depths and depth settings can also be computed.

$$CORR_{wl} = D_{wl} - D_v = \left(0.0004081 - 0.0001471 \times P + 0.00005731 \times P^2\right) \times D_{wl}, \quad (8)$$

where $CORR_{wl}$ the correction, in feet, to subtract from the wet-line depth to obtain the vertical depth,

D_{wl} the wet-line depth, in feet,

D_v the vertical depth, in feet, and

P the vertical angle, in degrees.

If the direction of flow is not perpendicular to the measuring section, the observed angle in the measuring line as indicated by a protractor will be less than the true angle of the line. The air correction and wet-line correction will then be too small. To correct for this, measure the horizontal angle between the direction of flow and a perpendicular to the measuring section with a protractor, or determine the horizontal angle coefficient as described in a subsequent section of this publication. The geometry of this condition is illustrated in figure 11.

If the horizontal angle of the direction of flow is called H , the observed vertical angle P , and the true vertical angle X , the relation between the angles is expressed by the equation

$$\tan X = \frac{\tan P}{\cos H}. \quad (9)$$

Table 4 gives the amounts in tenths of degrees. Add these to observed vertical angles to obtain the true vertical angles for a range of horizontal angles between 8 degrees and 28 degrees.

The conditions that cause error in sounding the depth also cause error in the placement of the meter at selected depths. The correction tables are not strictly applicable to the problem of placing the meter because of the increased pressure placed on the sounding weight by higher velocities when it is raised from the streambed. A meter placed in deep, swift water by the ordinary methods for observations at selected percentages of the depth will be too high in the water. The use of tables 2 and 3 will tend to eliminate this error in placement of the meter, and although not strictly applicable, their use for this purpose has become general.

For the 0.2-depth position, the curvature of the wet line is assumed to be negligible and the length of sounding line from the apex of the vertical angle to the weight is considered to be a straight line. The method used to place the meter at the 0.2-depth position is as follows:

1. Compute the 0.2 value of the vertical depth.
2. Lower the meter to this depth into the water and read the vertical angle.
3. Obtain the air correction from table 2. The vertical length used to obtain the air correction is the sum of (a) 0.2 of the vertical depth, (b) the distance from the water surface to the apex of the angle, and (c) the distance from the bottom of the weight to the meter.
4. Let out an additional amount of line equal to the air correction.

16 Discharge Measurements at Gaging Stations

Table 2. Air correction table (in feet), giving differences between vertical length and slant length of sounding line above water surface for selected vertical angles.

Vertical length (feet)	Vertical angle of sounding line at protractor																Vertical length (feet)	
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°		36°
10	0.02	0.06	0.10	0.15	0.22	0.31	0.40	0.51	0.64	0.79	0.95	1.13	1.33	1.55	1.79	2.06	2.36	10
12	0.03	0.07	0.12	0.19	0.27	0.37	0.48	0.62	0.77	0.94	1.14	1.35	1.59	1.86	2.15	2.47	2.83	12
14	0.03	0.08	0.14	0.22	0.31	0.43	0.56	0.72	0.90	1.10	1.32	1.58	1.86	2.17	2.51	2.89	3.30	14
16	0.04	0.09	0.16	0.25	0.36	0.49	0.64	0.82	1.03	1.26	1.51	1.80	2.12	2.48	2.87	3.30	3.78	16
18	0.04	0.10	0.18	0.28	0.40	0.55	0.73	0.93	1.16	1.41	1.70	2.03	2.39	2.78	3.23	3.71	4.25	18
20	0.05	0.11	0.20	0.31	0.45	0.61	0.81	1.03	1.28	1.57	1.89	2.25	2.65	3.09	3.58	4.12	4.72	20
22	0.05	0.12	0.22	0.34	0.49	0.67	0.89	1.13	1.41	1.73	2.08	2.48	2.92	3.40	3.94	4.54	5.19	22
24	0.06	0.13	0.24	0.37	0.54	0.73	0.97	1.24	1.54	1.88	2.27	2.70	3.18	3.71	4.30	4.95	5.67	24
26	0.06	0.14	0.26	0.40	0.58	0.80	1.05	1.34	1.67	2.04	2.46	2.93	3.45	4.02	4.66	5.36	6.14	26
28	0.07	0.15	0.28	0.43	0.63	0.86	1.13	1.44	1.80	2.20	2.65	3.15	3.71	4.33	5.02	5.77	6.61	28
30	0.07	0.17	0.29	0.46	0.67	0.92	1.21	1.54	1.93	2.36	2.84	3.38	3.98	4.64	5.38	6.19	7.08	30
32	0.08	0.18	0.31	0.49	0.71	0.98	1.29	1.65	2.05	2.51	3.03	3.60	4.24	4.95	5.73	6.60	7.55	32
34	0.08	0.19	0.33	0.52	0.76	1.04	1.37	1.75	2.18	2.67	3.22	3.83	4.51	5.26	6.09	7.01	8.03	34
36	0.09	0.20	0.35	0.56	0.80	1.10	1.45	1.85	2.31	2.83	3.41	4.05	4.77	5.57	6.45	7.42	8.50	36
38	0.09	0.21	0.37	0.59	0.85	1.16	1.53	1.96	2.44	2.98	3.60	4.28	5.04	5.88	6.81	7.84	8.97	38
40	0.10	0.22	0.39	0.62	0.89	1.22	1.61	2.06	2.57	3.14	3.79	4.50	5.30	6.19	7.17	8.25	9.44	40
42	0.10	0.23	0.41	0.65	0.94	1.29	1.69	2.16	2.70	3.30	3.97	4.73	5.57	6.50	7.53	8.66	9.91	42
44	0.11	0.24	0.43	0.68	0.98	1.35	1.77	2.26	2.82	3.46	4.16	4.95	5.83	6.81	7.88	9.07	10.39	44
46	0.11	0.25	0.45	0.71	1.03	1.41	1.85	2.37	2.95	3.61	4.35	5.18	6.10	7.12	8.24	9.49	10.86	46
48	0.12	0.26	0.47	0.74	1.07	1.47	1.93	2.47	3.08	3.77	4.54	5.40	6.36	7.43	8.60	9.90	11.33	48
50	0.12	0.28	0.49	0.77	1.12	1.53	2.02	2.57	3.21	3.93	4.73	5.63	6.63	7.74	8.96	10.31	11.80	50
52	0.13	0.29	0.51	0.80	1.16	1.59	2.10	2.68	3.34	4.08	4.92	5.86	6.89	8.04	9.32	10.72	12.28	52
54	0.13	0.30	0.53	0.83	1.21	1.65	2.18	2.78	3.47	4.24	5.11	6.08	7.16	8.35	9.68	11.14	12.75	54
56	0.14	0.31	0.55	0.86	1.25	1.71	2.26	2.88	3.59	4.40	5.30	6.31	7.42	8.66	10.03	11.55	13.22	56
58	0.14	0.32	0.57	0.89	1.30	1.78	2.34	2.98	3.72	4.55	5.49	6.53	7.69	8.97	10.39	11.96	13.69	58
60	0.15	0.33	0.59	0.93	1.34	1.84	2.42	3.09	3.85	4.71	5.68	6.76	7.95	9.28	10.75	12.37	14.16	60
62	0.15	0.34	0.61	0.96	1.39	1.90	2.50	3.19	3.98	4.87	5.87	6.98	8.22	9.59	11.11	12.79	14.64	62
64	0.16	0.35	0.63	0.99	1.43	1.96	2.58	3.29	4.11	5.03	6.06	7.21	8.48	9.90	11.47	13.20	15.11	64
66	0.16	0.36	0.65	1.02	1.47	2.02	2.66	3.40	4.24	5.18	6.25	7.43	8.75	10.21	11.83	13.61	15.58	66
68	0.17	0.37	0.67	1.05	1.52	2.08	2.74	3.50	4.36	5.34	6.44	7.66	9.01	10.52	12.18	14.02	16.05	68
70	0.17	0.39	0.69	1.08	1.56	2.14	2.82	3.60	4.49	5.50	6.62	7.88	9.28	10.83	12.54	14.44	16.52	70
72	0.18	0.40	0.71	1.11	1.61	2.20	2.90	3.71	4.62	5.65	6.81	8.11	9.55	11.14	12.90	14.85	17.00	72
74	0.18	0.41	0.73	1.14	1.65	2.27	2.98	3.81	4.75	5.81	7.00	8.33	9.81	11.45	13.26	15.26	17.47	74
76	0.19	0.42	0.75	1.17	1.70	2.33	3.06	3.91	4.88	5.97	7.19	8.56	10.08	11.76	13.62	15.67	17.94	76
78	0.19	0.43	0.77	1.20	1.74	2.39	3.14	4.01	5.01	6.13	7.38	8.78	10.34	12.07	13.98	16.09	18.41	78
80	0.20	0.44	0.79	1.23	1.79	2.45	3.22	4.12	5.13	6.28	7.57	9.01	10.61	12.38	14.33	16.50	18.89	80
82	0.20	0.45	0.81	1.27	1.83	2.51	3.30	4.22	5.26	6.44	7.76	9.23	10.87	12.69	14.69	16.91	19.36	82
84	0.20	0.46	0.83	1.30	1.88	2.57	3.39	4.32	5.39	6.60	7.95	9.46	11.14	12.99	15.05	17.32	19.83	84
86	0.21	0.47	0.85	1.33	1.92	2.63	3.47	4.43	5.52	6.75	8.14	9.68	11.40	13.30	15.41	17.73	20.30	86
88	0.21	0.48	0.87	1.36	1.97	2.69	3.55	4.53	5.65	6.91	8.33	9.91	11.67	13.61	15.77	18.15	20.77	88
90	0.22	0.50	0.88	1.39	2.01	2.75	3.63	4.63	5.78	7.07	8.52	10.13	11.93	13.92	16.13	18.56	21.25	90
92	0.22	0.51	0.90	1.42	2.06	2.82	3.71	4.73	5.90	7.22	8.71	10.36	12.20	14.23	16.48	18.97	21.72	92
94	0.23	0.52	0.92	1.45	2.10	2.88	3.79	4.84	6.03	7.38	8.90	10.58	12.46	14.54	16.84	19.38	22.19	94
96	0.23	0.53	0.94	1.48	2.14	2.94	3.87	4.94	6.16	7.54	9.09	10.81	12.73	14.85	17.20	19.80	22.66	96
98	0.24	0.54	0.96	1.51	2.19	3.00	3.95	5.04	6.29	7.70	9.27	11.03	12.99	15.16	17.56	20.21	23.13	98
100	0.24	0.55	0.98	1.54	2.23	3.06	4.03	5.15	6.42	7.85	9.46	11.26	13.26	15.47	17.92	20.62	23.61	100

Table 3. Wet-line table (in feet) giving differences between wet-line length and vertical depth for selected vertical angles.

Wet-line length (feet)	Vertical angle of sounding line at protractor																Wet-line length (feet)	
	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	34°		36°
10	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.25	0.30	0.35	0.41	0.47	0.54	0.62	0.70	10
12	0.01	0.02	0.04	0.06	0.09	0.12	0.15	0.20	0.24	0.30	0.36	0.42	0.49	0.57	0.65	0.74	0.84	12
14	0.01	0.02	0.04	0.07	0.10	0.14	0.18	0.23	0.29	0.35	0.41	0.49	0.57	0.66	0.76	0.87	0.98	14
16	0.01	0.03	0.05	0.08	0.12	0.16	0.20	0.26	0.33	0.40	0.47	0.56	0.65	0.76	0.87	0.99	1.12	16
18	0.01	0.03	0.06	0.09	0.13	0.18	0.23	0.30	0.37	0.45	0.53	0.63	0.73	0.85	0.98	1.12	1.26	18
20	0.01	0.03	0.06	0.10	0.14	0.20	0.26	0.33	0.41	0.50	0.59	0.70	0.82	0.94	1.09	1.24	1.40	20
22	0.01	0.04	0.07	0.11	0.16	0.22	0.28	0.36	0.45	0.55	0.65	0.77	0.90	1.04	1.20	1.36	1.54	22
24	0.01	0.04	0.08	0.12	0.17	0.24	0.31	0.39	0.49	0.60	0.71	0.84	0.98	1.13	1.31	1.49	1.68	24
26	0.02	0.04	0.08	0.13	0.19	0.25	0.33	0.43	0.53	0.64	0.77	0.91	1.06	1.23	1.41	1.61	1.81	26
28	0.02	0.04	0.09	0.14	0.20	0.27	0.36	0.46	0.57	0.69	0.83	0.98	1.14	1.32	1.52	1.74	1.95	28
30	0.02	0.05	0.10	0.15	0.22	0.29	0.38	0.49	0.61	0.74	0.89	1.05	1.22	1.42	1.63	1.86	2.09	30
32	0.02	0.05	0.10	0.16	0.23	0.31	0.41	0.52	0.65	0.79	0.95	1.12	1.31	1.51	1.74	1.98	2.23	32
34	0.02	0.05	0.11	0.17	0.24	0.33	0.44	0.56	0.69	0.84	1.01	1.19	1.39	1.60	1.85	2.11	2.37	34
36	0.02	0.06	0.12	0.18	0.26	0.35	0.46	0.59	0.73	0.89	1.07	1.26	1.47	1.70	1.96	2.23	2.51	36
38	0.02	0.06	0.12	0.19	0.27	0.37	0.49	0.62	0.78	0.94	1.12	1.33	1.55	1.79	2.07	2.36	2.65	38
40	0.02	0.06	0.13	0.20	0.29	0.39	0.51	0.66	0.82	0.99	1.18	1.40	1.63	1.89	2.18	2.48	2.79	40
42	0.03	0.07	0.13	0.21	0.30	0.41	0.54	0.69	0.86	1.04	1.24	1.47	1.71	1.98	2.28	2.60	2.93	42
44	0.03	0.07	0.14	0.22	0.32	0.43	0.56	0.72	0.90	1.09	1.30	1.54	1.80	2.08	2.39	2.73	3.07	44
46	0.03	0.07	0.15	0.23	0.33	0.45	0.59	0.75	0.94	1.14	1.36	1.61	1.88	2.17	2.50	2.85	3.21	46
48	0.03	0.08	0.15	0.24	0.35	0.47	0.61	0.79	0.98	1.19	1.42	1.68	1.96	2.27	2.61	2.98	3.35	48
50	0.03	0.08	0.16	0.25	0.36	0.49	0.64	0.82	1.02	1.24	1.48	1.75	2.04	2.36	2.72	3.10	3.49	50
52	0.03	0.08	0.17	0.26	0.37	0.51	0.67	0.85	1.06	1.29	1.54	1.82	2.12	2.45	2.83	3.22	3.63	52
54	0.03	0.09	0.17	0.27	0.39	0.53	0.69	0.89	1.10	1.34	1.60	1.89	2.20	2.55	2.94	3.35	3.77	54
56	0.03	0.09	0.18	0.28	0.40	0.55	0.72	0.92	1.14	1.39	1.66	1.96	2.28	2.64	3.05	3.47	3.91	56
58	0.03	0.09	0.19	0.29	0.42	0.57	0.74	0.95	1.18	1.44	1.72	2.03	2.37	2.74	3.16	3.60	4.05	58
60	0.04	0.10	0.19	0.30	0.43	0.59	0.77	0.98	1.22	1.49	1.78	2.10	2.45	2.83	3.26	3.72	4.19	60
62	0.04	0.10	0.20	0.31	0.45	0.61	0.79	1.02	1.26	1.54	1.84	2.17	2.53	2.93	3.37	3.84	4.33	62
64	0.04	0.10	0.20	0.32	0.46	0.63	0.82	1.05	1.31	1.59	1.89	2.24	2.61	3.02	3.48	3.97	4.47	64
66	0.04	0.11	0.21	0.33	0.48	0.65	0.84	1.08	1.35	1.64	1.95	2.31	2.69	3.12	3.59	4.09	4.61	66
68	0.04	0.11	0.22	0.34	0.49	0.67	0.87	1.12	1.39	1.69	2.01	2.38	2.77	3.21	3.70	4.22	4.75	68
70	0.04	0.11	0.22	0.35	0.50	0.69	0.90	1.15	1.43	1.74	2.07	2.45	2.86	3.30	3.81	4.34	4.89	70
72	0.04	0.12	0.23	0.36	0.52	0.71	0.92	1.18	1.47	1.79	2.13	2.52	2.94	3.40	3.92	4.46	5.03	72
74	0.04	0.12	0.24	0.37	0.53	0.73	0.95	1.21	1.51	1.84	2.19	2.59	3.02	3.49	4.03	4.59	5.17	74
76	0.05	0.12	0.24	0.38	0.55	0.74	0.97	1.25	1.55	1.88	2.25	2.66	3.10	3.59	4.13	4.71	5.30	76
78	0.05	0.12	0.25	0.39	0.56	0.76	1.00	1.28	1.59	1.93	2.31	2.73	3.18	3.68	4.24	4.84	5.44	78
80	0.05	0.13	0.25	0.40	0.58	0.78	1.02	1.31	1.63	1.98	2.37	2.80	3.26	3.78	4.35	4.96	5.58	80
82	0.05	0.13	0.26	0.41	0.59	0.80	1.05	1.34	1.67	2.03	2.43	2.87	3.35	3.87	4.46	5.08	5.72	82
84	0.05	0.13	0.27	0.42	0.60	0.82	1.08	1.38	1.71	2.08	2.49	2.94	3.43	3.96	4.57	5.21	5.86	84
86	0.05	0.14	0.28	0.43	0.62	0.84	1.10	1.41	1.75	2.13	2.55	3.01	3.51	4.06	4.68	5.33	6.00	86
88	0.05	0.14	0.28	0.44	0.63	0.86	1.13	1.44	1.80	2.18	2.60	3.08	3.59	4.15	4.79	5.46	6.14	88
90	0.05	0.14	0.29	0.45	0.65	0.88	1.15	1.48	1.84	2.23	2.66	3.15	3.67	4.25	4.90	5.58	6.28	90
92	0.06	0.15	0.29	0.46	0.66	0.90	1.18	1.51	1.88	2.28	2.72	3.22	3.75	4.34	5.00	5.70	6.42	92
94	0.06	0.15	0.30	0.47	0.68	0.92	1.20	1.54	1.92	2.33	2.78	3.29	3.84	4.44	5.11	5.83	6.56	94
96	0.06	0.15	0.31	0.48	0.69	0.94	1.23	1.57	1.96	2.38	2.84	3.36	3.92	4.53	5.22	5.95	6.70	96
98	0.06	0.16	0.31	0.49	0.71	0.96	1.25	1.61	2.00	2.43	2.90	3.43	4.00	4.63	5.33	6.08	6.84	98
100	0.06	0.16	0.32	0.50	0.72	0.98	1.28	1.64	2.04	2.48	2.96	3.50	4.08	4.72	5.44	6.20	6.98	100

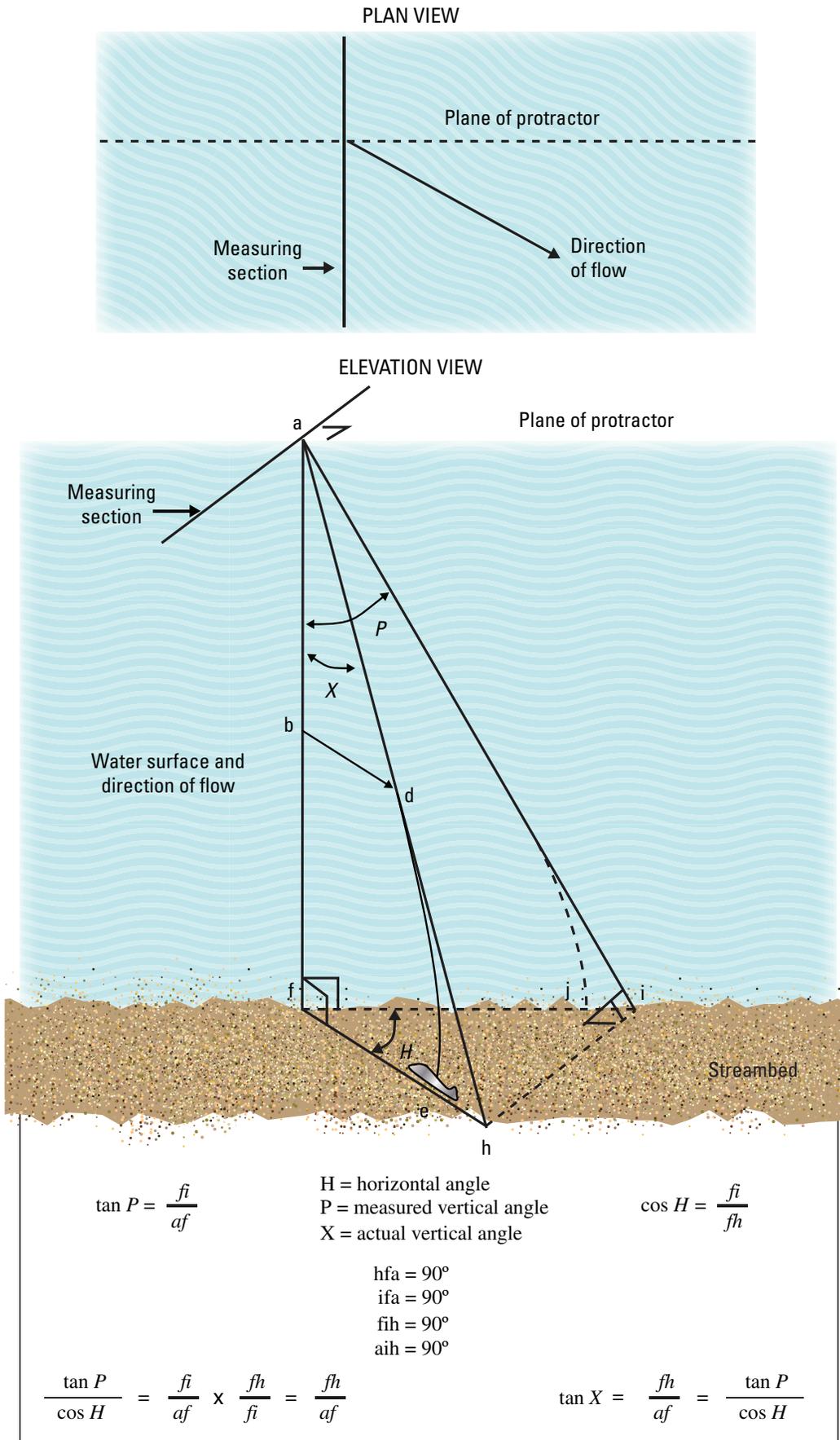


Figure 11. Sketch of geometric relationship of actual to measured vertical angle when flow direction is not normal to the measuring section.

- If the angle increases appreciably when the additional line is let out, let out more line until the total additional line, the angle, and the vertical distance are in agreement with values presented in the air-correction table.

To place the meter at the 0.8-depth position, a correction to the amount of line reeled in must be made for the difference, if any, between the air correction for the sounding position and that for the 0.8-depth position. This difference is designated as *m* in table 5. If the angle increases for the 0.8-depth position, the meter must be lowered; if it decreases, the meter must be raised.

For the 0.8-depth position of the meter, the wet-line correction may require consideration if the depths are more than 40 ft and if the change in vertical angle is more than 5 percent. If the vertical angle remains the same or decreases, the wet-line correction (table 3) for the 0.8-depth position is less than the wet-line correction for the sounding position by some difference, designated as *n* in table 5. If the vertical angle increases, the difference in correction *n* diminishes until the increase in angle is about 10 percent; for greater increases in angle, the difference between corrections increases also. Table 5 summarizes the effect on air and wet-line corrections caused by raising the meter from the sounding position to the 0.8-depth position.

For slight changes in the vertical angle, because of the differences *m* and *n* in the air and wet-line corrections, the adjustments

to the wet-line length of the 0.8-depth position are small and usually can be ignored. Table 5 indicates that the meter may be placed a little too deep if the adjustments are not made. Because of this possibility, the wet-line depth instead of the vertical depth is sometimes used as the basis for computing the 0.8-depth position with no adjustments for the differences *m* and *n*.

Use of Sonic Sounder

The sonic sounder has been used primarily for measuring depth when making a moving boat measurement and in ADCP discharge measurements, and is generally not utilized for measurements where sounding weights are used. However, it can be used in swift, debris-laden streams, where it is difficult or dangerous to lower the sounding weight and meter into the water. The sonic sounder will record the depth when the weight is just below the water surface. For moving boat measurements, the sonic sounder records a continuous trace of the streambed on a digital or analog chart. Details of the setup and use can be found in Smoot and Novak (1969). Relevant information on the use of acoustic sounders in a riverine environment is discussed in detail in Mueller and Landers (1999) and by the International Organization for Standardization (2003). For use of a sonic sounder in ADCP measurements, consult Mueller and Wagner (2009).

Table 4. Degrees to be added to observed vertical angle, *P*, to obtain true vertical angle when flow direction is not normal to measurement section.

Observed vertical angle, <i>P</i> , in degrees	Horizontal angle, <i>H</i> , in degrees					
	8 cos = 0.99	12 cos = 0.98	16 cos = 0.96	20 cos = 0.94	24 cos = 0.91	28 cos = 0.88
8	0.1	0.2	0.3	0.5	0.8	1.0
12	0.1	0.3	0.5	0.8	1.1	1.5
16	0.1	0.4	0.6	1.0	1.4	2.0
20	0.2	0.4	0.7	1.2	1.7	2.4
24	0.2	0.5	0.8	1.4	2.0	2.8
28	0.2	0.5	1.0	1.5	2.2	3.0
32	0.2	0.6	1.0	1.6	2.4	3.3
36	0.2	0.6	1.1	1.7	2.5	3.4

Table 5. Summary table for setting the meter at 0.8-depth position in deep, swift streams.

Change in vertical angle	Air correction		Wet-line correction	
	Direction of change	Correction to meter position	Direction of change	Correction to meter position
None	None	None	Decrease	Raise meter the distance <i>n</i>
Decrease	Decrease	Raise meter the distance <i>m</i>	Decrease	Raise meter the distance <i>n</i>
Increase	Increase	Lower meter the distance <i>m</i>	Decrease, then increase	¹

¹Raise meter the distance *n* unless the increase in angle is greater than about 10 percent, then it is necessary to lower the meter the distance *n*.

Measurement of Velocity

With point-velocity meters, after the width and depth at a vertical are measured and recorded, determine the method of velocity measurement. Normally the two-point method or the 0.6-depth method is used. Details of velocity measurement methods using various equipment and under different flow conditions are described in subsequent sections of this chapter.

Compute the setting of the meter for the particular method that will be used at that depth. For the top-setting wading rod, or the spiral-computing dial, some meter settings are self-computing. Record the meter position as 0.8, 0.6, 0.2, or another setting. After the meter is placed at the proper depth, let it adjust to the current before starting the velocity observation. With an ADV, make sure the instrument is located perpendicular to the tag line and the wading rod is plumbed (that is, vertical to the channel bed) before beginning measurement. The time required for adjustment to the undisturbed stream velocity is usually only a few seconds if the velocities are greater than 1 ft/s; however, for lower velocities, particularly if the current meter is suspended by a cable, a longer period of adjustment is needed. After the meter has become adjusted to the current, count the number of revolutions made by the rotor for a period of 40 to 70 seconds; for an ADV, this time period is typically programmed into the instrument's discharge measurement software.

If using a stopwatch to time the revolutions of a mechanical current meter, start the stopwatch simultaneously with the first signal or click, counting "zero," not "one." End the count on a convenient number given in the mechanical current meter rating table column heading. Stop the stopwatch on that count and read the time to the nearest second. Record the number of revolutions and the time interval. If the velocity is to be observed at more than one point in the vertical, determine the meter setting for the additional observation, set the meter to that depth, time the revolutions, and record the data.

When using a current meter digitizer (CMD), a personal digital assistant (PDA), or an electronic notebook such as the Aquacalc or an ADV, observe the same basic procedure for setting the meter, and for providing time for the meter to stabilize. With these instruments, however, the counting and timing of the rotor revolutions or the acoustic pulse measurement are performed automatically. The number of revolutions, time, and velocity displayed by the CMD must be transferred manually to paper field notes, whereas, these data are electronically recorded by the Aquacalc, a PDA, or an ADV. When using any of these automatic meter counting devices and a mechanical current meter, make sure that multiple counts are not occurring during measurement of slow velocity. This can sometimes be determined by visually observing the rotation of the rotor while simultaneously listening to the audible clicks or beeps from the counting device. With the ADV, instead of audible clicks, acoustic Doppler theory is applied. The ADV can sense and measure velocities much smaller than those

rated and measured by mechanical meters and are not prone to the multiple count errors of the mechanical current meter.

Current meters, in general, measure stream velocity at a point. One notable exception is the ADCP. This method will be discussed in a subsequent section of this chapter; a thorough discussion of a moving boat discharge measurement using an ADCP is documented in Mueller and Wagner (2009).

The method of making discharge measurements at a cross section by using a current meter that measures point velocities requires determination of the mean velocity in each of the selected verticals. The mean velocity in a vertical is obtained from velocity observations at several points in that vertical. The mean velocity can be approximated by making a few velocity observations and using a known relation between those velocities and the mean in the vertical. The various methods of measuring velocity are: vertical-velocity curve, two-point, 0.6-depth, 0.2-depth, three-point, and surface and subsurface.

Vertical-Velocity Curve Method

In the vertical-velocity curve method, a series of velocity observations at points well distributed between the water surface and the streambed are made at each of the verticals. If there is considerable curvature in the lower part of the vertical-velocity curve, then it is advisable to space the observations more closely together in that part of the depth. Normally, the observations are taken at 0.1-depth increments between 0.1 and 0.9 of the depth. Observations are always taken at 0.2, 0.6, and 0.8 of the depth so that the results obtained by the vertical-velocity curve method may be compared with the commonly used methods of velocity observation. Observations are made at least 0.5 ft from the water surface and from the streambed with the Price AA meter, at least 0.3 ft from these boundaries with the Price pygmy meter, or at least 0.2 ft from these boundaries with the FlowTracker ADV.

The vertical-velocity curve for each vertical is based on observed velocities plotted against depth, as shown in figure 12. In order that vertical-velocity curves at different verticals may be readily compared, it is customary to plot depths as proportional parts of the total depth. The mean velocity in the vertical is obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and dividing the area by the length of the ordinate axis.

The vertical-velocity curve method is valuable in determining coefficients for application to the results obtained by other methods, but is not generally adapted to routine discharge measurements because of the extra time required to collect field data and to compute the mean velocity. A typical vertical-velocity curve for the cross section should be measured and evaluated at all new measurement sites, and perhaps at new measurement sections if the new section is significantly different in hydraulic characteristics than the section normally used at a regular measurement site.

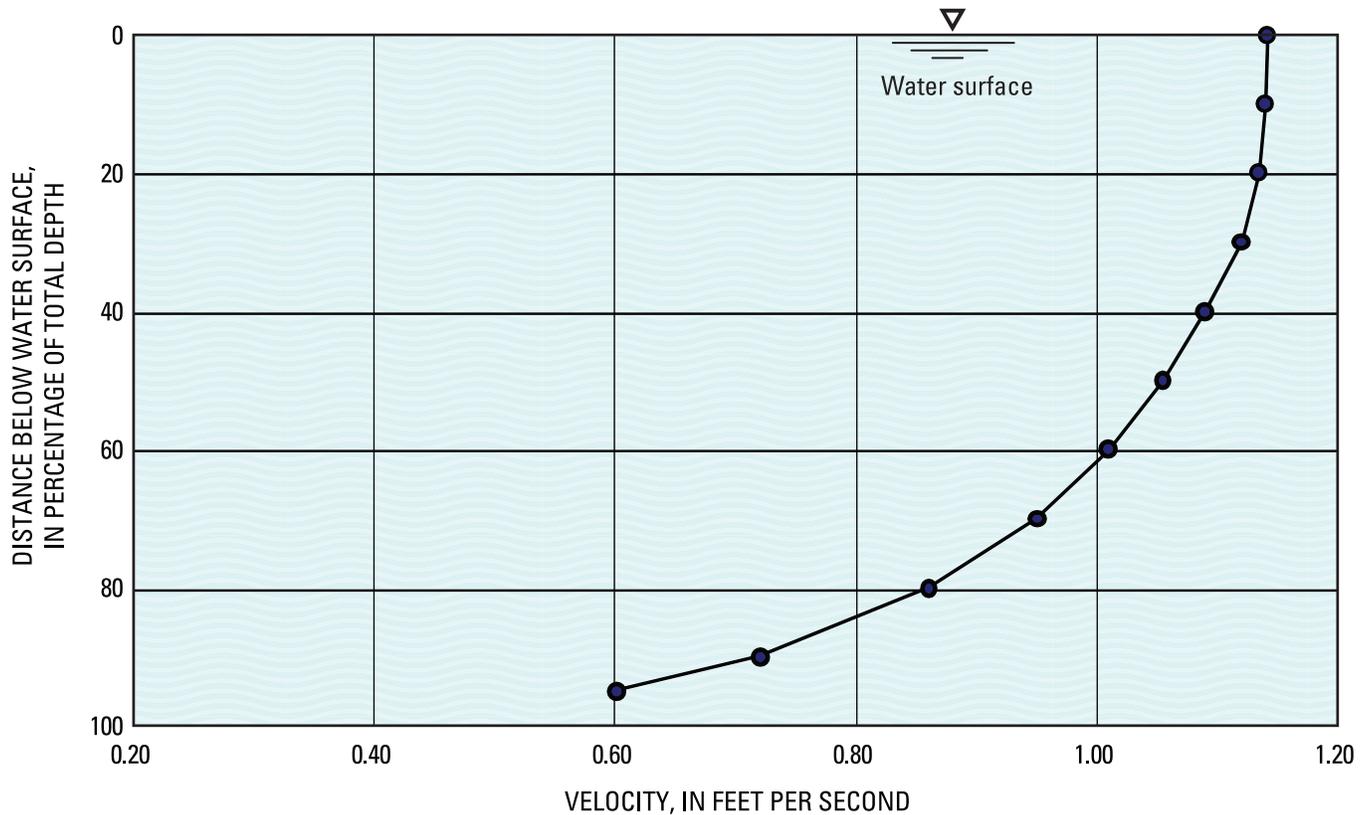


Figure 12. Typical vertical-velocity curve.

Two-Point Method

This is the preferred method for making midsection discharge measurements with point velocity meters. In the two-point method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface. The average of these two observations is used as the mean velocity in the vertical. This method is based on many studies of actual observation and on mathematical theory. Experience has shown that this method gives more consistent and accurate results than any of the other methods, except for the vertical-velocity curve method. Use the two-point method for depths of 2.5 ft or greater, unless using a pygmy current meter or an ADV, in which case, this method is used in depths of 1.5 ft or greater.

With an ADV, the actual instrument has much less drag or resistance to the flow as compared to a mechanical current meter. To prevent boundary interference, avoid placing the ADV sample volume [typically 10 centimeters (about 4 in.) from the center transmitting transducer] within 2 in. from any solid boundary. This boundary condition with the ADV allows for measurement of velocity closer to the water surface and channel bed than a Price AA or to the pygmy (fig. 13). With the Price AA current meter, the two-point method is not used at depths less than 2.5 ft because the current meter would be too close to the water surface and to the streambed to give dependable results.

Six-Tenths-Depth Method

In the 0.6-depth method, an observation of velocity made at 0.6 of the depth below the water surface in the vertical is used as the mean velocity in the vertical. Actual observation and mathematical theory have shown that the 0.6-depth method gives reliable results and is used by the USGS under the following conditions:

Price AA Current Meter

1. Whenever the depth is between 0.3 ft and 2.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the meter is placed a distance above the sounding weight, which makes it impossible to place the meter at the 0.8 depth. (This condition prevents the use of the two-point method.)
4. When the stage in a stream is changing rapidly and you must make a quick measurement.

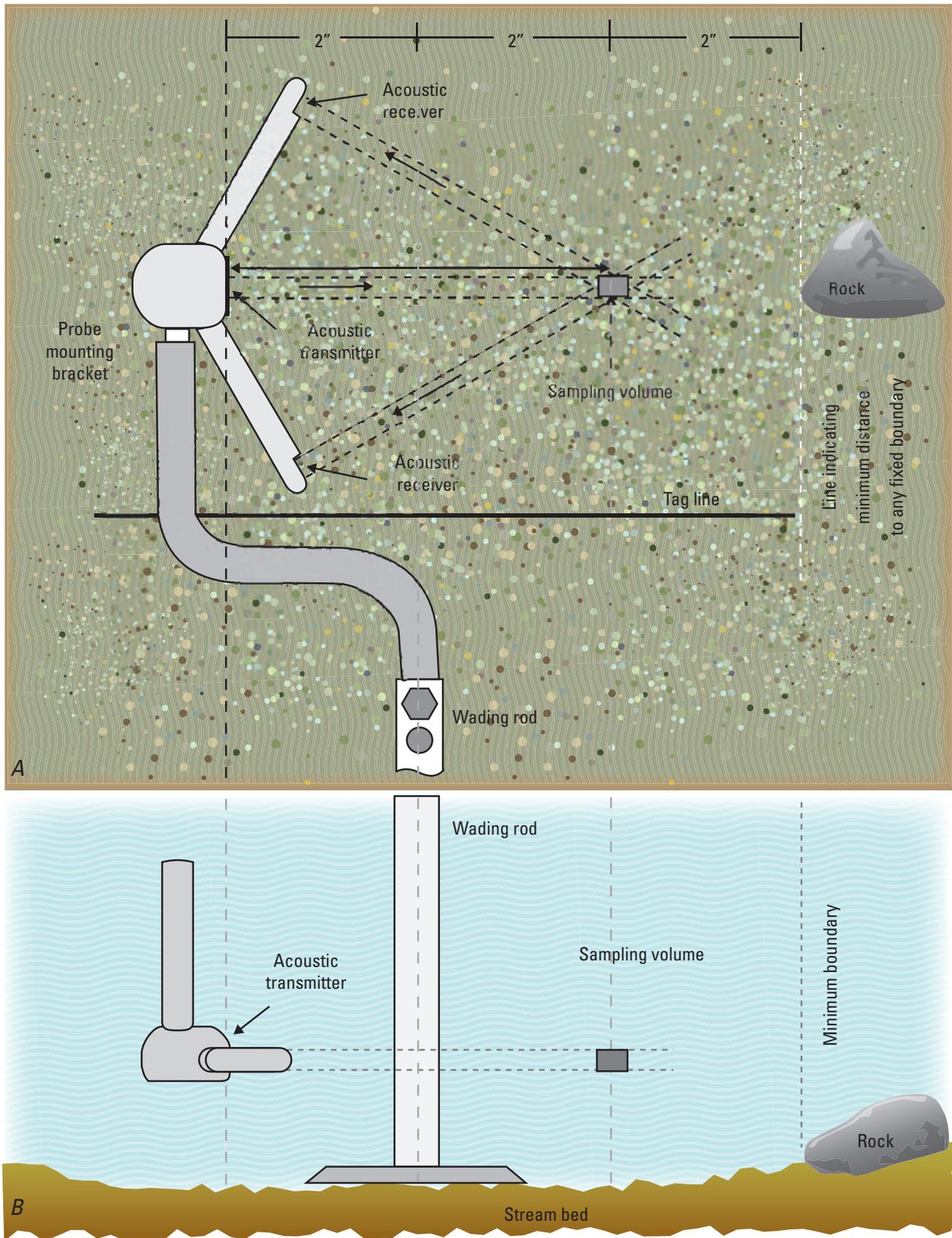


Figure 13. Schematic showing A, plan view and B, cross section of the FlowTracker sampling volume and the proximity to a fixed boundary in the stream. (Note: Probe mounting bracket not shown.)

Pygmy Current Meter

1. Whenever the depth is between 0.3 ft and 1.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Acoustic Doppler Velocimeter

1. Whenever the depth is between 0.25 ft and 1.5 ft.
2. When large amounts of slush ice or debris make it impossible to observe the velocity accurately at the 0.2 depth. (This condition prevents the use of the two-point method.)
3. When the stage in a stream is changing rapidly and a measurement must be made quickly.

Two-Tenths-Depth Method

The 0.2-depth method consists of observing the velocity at 0.2 of the depth below the surface and applying a coefficient to this observed velocity to obtain the mean in the vertical. It is used mainly during times of high water when the velocities are great, making it impossible to obtain soundings or to place the meter at the 0.8 or the 0.6 depth.

Use a standard cross section or a general knowledge of the cross section at a site to compute the 0.2 depth when it is impossible to obtain depth soundings. A sizeable error in an assumed 0.2 depth is not critical because the slope of the vertical-velocity curve at this point is usually nearly vertical. The 0.2 depth is also used in conjunction with the sonic sounder for flood measurements. The two-point method and the 0.6-depth method are preferred over the 0.2-depth method because of their greater accuracy.

The discharge measurement is normally computed by using the 0.2-depth velocity observations without coefficients as though each were a mean in the vertical. The approximate discharge thus obtained divided by the area of the measuring section gives the weighted mean value of the 0.2-depth velocity. Studies of many measurements made by the two-point method show that for a given measuring section, the relation between the mean 0.2-depth velocity and the true mean velocity either remains constant or varies uniformly with stage. In either circumstance, this relation may be determined for a particular 0.2-depth measurement by recomputing measurements made at the site by the two-point method using only the 0.2-depth velocity observation as the mean in the vertical. The plotting of the true mean velocity versus the mean 0.2-depth velocity for each measurement will give a velocity-relation curve for use in adjusting the mean velocity for measurements made by the 0.2-depth method.

If not enough measurements by the two-point method are available at a site to establish a velocity-relation curve, vertical-velocity curves are needed to establish a relation between the mean velocity and the 0.2-depth velocity. The usual coefficient to adjust the 0.2-depth velocity to the mean velocity is about 0.88.

Three-Point Method

The three-point method consists of observing the velocity at 0.2, 0.6, and 0.8 of the depth, thereby combining the two-point and 0.6-depth methods. The preferred method of computing the mean velocity is to average the 0.2- and 0.8-depth observations and then average this result with the 0.6-depth observation. However, when more weight to the 0.2- and 0.8-depth observations is desired, the arithmetic mean of the three observations may be used.

The three-point method is used when the velocities in the vertical are abnormally distributed [for example, the 0.2 (top) velocity is more than twice the 0.8 (bottom) velocity, or the 0.8 (bottom) velocity is greater than the 0.2 (top) velocity]. It is also used when the 0.8-depth observation is made where the velocity is seriously affected by friction or by turbulence produced by the streambed or an obstruction in the stream. If using a Price AA, the depths must be greater than 2.5 ft to use this method. If using a Price pygmy or ADV, the depths must be greater than 1.5 ft to use this method.

Surface and Subsurface Methods

Surface and subsurface methods consist of observing the velocity at the water surface or some distance below the water surface. Surface measurements may be made with the optical current meter, or by observing and timing surface floats. Subsurface measurements are made with a current meter at a distance of at least 2 ft below the surface to avoid the effect of surface disturbances. Surface and subsurface measurements are used primarily for deep swift streams where it is impossible or dangerous to obtain depth and velocity soundings at the regular 0.2, 0.6, and 0.8 depths.

Coefficients are necessary to convert the surface or subsurface velocities to the mean velocity in the vertical. Vertical-velocity curves obtained at the particular site are the best method to compute these coefficients. However, the coefficients are generally difficult to determine reliably because they may vary with stage, depth, and position in the measuring cross section. Experience has shown that the coefficients generally range from about 0.84 to about 0.90, depending on the shape of the vertical-velocity curve. The higher values are usually associated with smooth streambeds and normally shaped vertical-velocity curves, whereas the lower values are associated with irregular streambeds and irregular vertical-velocity curves.

Direction of Flow Measurements

Consider the direction of flow because the component of velocity normal to the measurement section is that which must be determined by both mechanical and acoustic Doppler point-velocity current meters. Generally, for the mechanical meter, the relation for velocity components not normal to the measuring section can be visualized in figure 14, and should be corrected using the cosine of alpha.

Flow direction is also critical with respect to an ADV, since the ADV assumes a horizontal and perpendicular plane to the flow. The hydrographer must pay close attention to the flow angle reported by the FlowTracker. Always hold the wading rod (with FlowTracker attached) perpendicular to the tag line so that the pulse generated by the transmitter is parallel to the tag line. Ideally, the tag line should be set up in the cross section to be measured so that flow is perpendicular to the tag line. Flow angle, as calculated by the FlowTracker, is defined as the direction of flow relative to the x -direction of flow, so that:

$$\text{FlowAngle} = \arctan(V_y / V_x), \quad (10)$$

where V_y is the velocity in the y direction (parallel to the tag line), and

V_x is the velocity in the x direction (perpendicular to the tag line) used to calculate discharge.

The flow angle calculated by the FlowTracker can result from two sources: (1) the flow is not perpendicular to the tag line, and (2) the flow is perpendicular to the tag line but the wading rod is not held correctly relative to the tag line, as described above. Regarding source (1), some small angles and variation in the flow angle at a site is not unusual. However, if large fluctuations of flow angles are reported, make measurements at another section with more uniform flow. Regarding source (2), holding the FlowTracker so that it is skewed at any angle relative to the tag line will result in a measurement of velocity that is biased low. Small angles do not result in significant biases, but because of these biases, users should be careful to minimize this error. If the FlowTracker is held so that it is skewed at an angle of approximately 8 degrees from the tag line, the measured velocity may be in error by as much as 1 percent (assuming that flow is perpendicular to the tag line). Large variations in flow angles may be indicative of poor or inconsistent alignment of the wading rod or poor site selection for the measurement.

In a wading measurement, if the meter used is a horizontal-axis meter with a component propeller, such as the Ott meter, the propeller should be pointed upstream at right angles to the cross section, but only if alpha is less than 45 degrees. Such a meter will register the desired component of velocity normal to the cross section when alpha is less than 45 degrees. The same procedure should be used if an electromagnetic component meter is used. These meters also measure the component of velocity normal to the measuring section. Generally, for either type of meter, if alpha is greater than 45 degrees, the component meter should be pointed directly into the current,

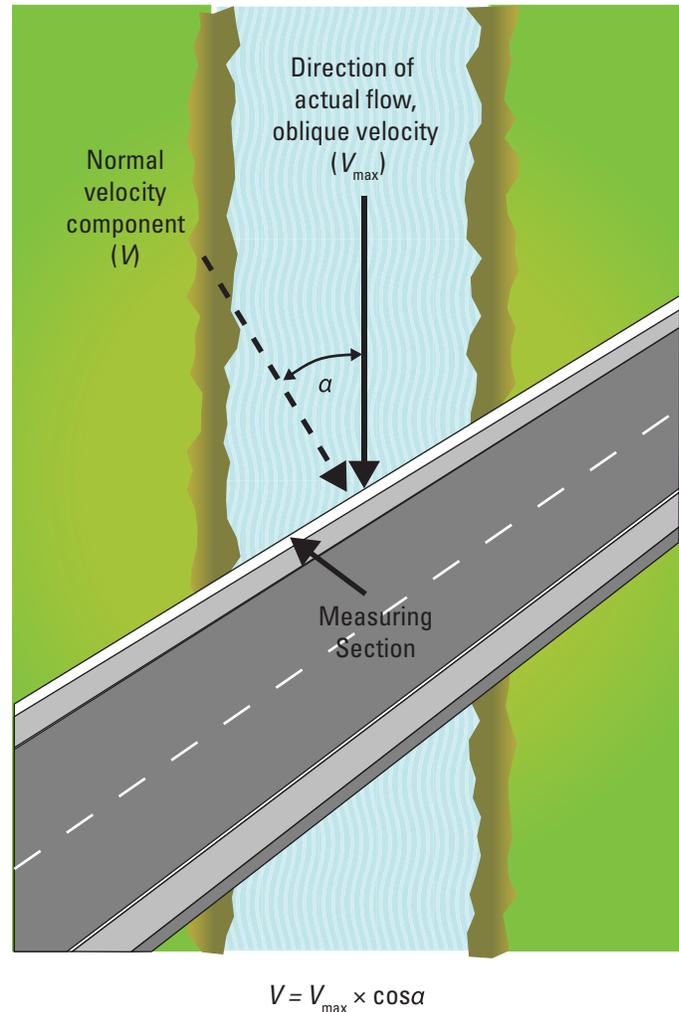


Figure 14. Velocity components when flow is not normal to measuring section.

and the horizontal angle correction should be applied as described in the following paragraphs.

Other meters on a wading-rod suspension, such as the vertical-axis Price current meter, should be pointed into the current. Any meter on a cable suspension will automatically point into the current because of the effect of the meter vanes. When the meter is pointed into an oblique current, the measured velocity must be multiplied by the cosine of the angle (alpha) between the current and a perpendicular to the measurement section in order to obtain the desired normal component of the velocity.

Either of two methods may be used to obtain the cosine of the angle alpha. In the first method, use the field note sheet that has a point of origin (O) printed on the left margin and cosine values on the right margin (see figure 2A). Measure the cosine of the angle of the current by holding the note sheet in a horizontal position with the point of origin on the tag line, bridge rail, cable rail, or any other feature parallel to the cross section, as shown in figure 15. With the long side of the note sheet parallel to the direction of flow, the tag line or bridge rail

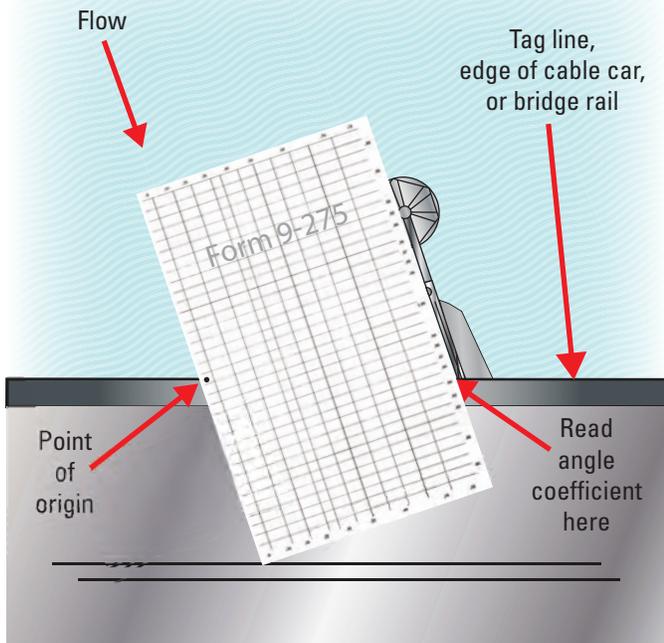


Figure 15. Measurement of horizontal angle with measurement note sheet.

will intersect the value of cosine alpha on the top, bottom, or right edge of the note sheet. The direction of the current will be apparent from the direction of movement of floating particles. If the water is clear of floating material, the edge of the note sheet is aligned parallel to the direction of movement. If no such material is available, the rather inelegant, but time-honored method of spitting into the stream can be used to discern the direction of flow. The position of the current meter may also be used if it can be seen below the water surface. Multiply the measured velocity by the cosine of the angle to determine the velocity component normal to the measurement section.

The second method of obtaining the cosine of the angle alpha involves the use of a folding rule that folds at 0.5-ft or 1-ft intervals. The rule must be graduated in hundredths of a foot and jointed every 0.5 ft or 1 ft. Extend the first 2 ft of the rule and place the 2.00-ft marker on the tag line or bridge rail, as shown in figure 16, with the rule aligned with the direction of flow. Fold the rule at the 1-ft mark so that the first foot of the rule is normal to the tag line or bridge rail. Make a reading where the 1-ft section intersects the tag line or bridge rail. That reading, subtracted from 1.00, is the cosine of the angle alpha. For example, if the reading on the rule is 0.07 ft (fig. 16), the cosine of alpha equals 0.93.

The direction of flow, as observed on the surface of the stream, may not always be a reliable indication of the direction of flow at some distance below the surface. For instance, when measuring a stream influenced by tidal fluctuations, it is possible to have flow moving downstream near the surface of the stream, and flow moving upstream near the bottom of the

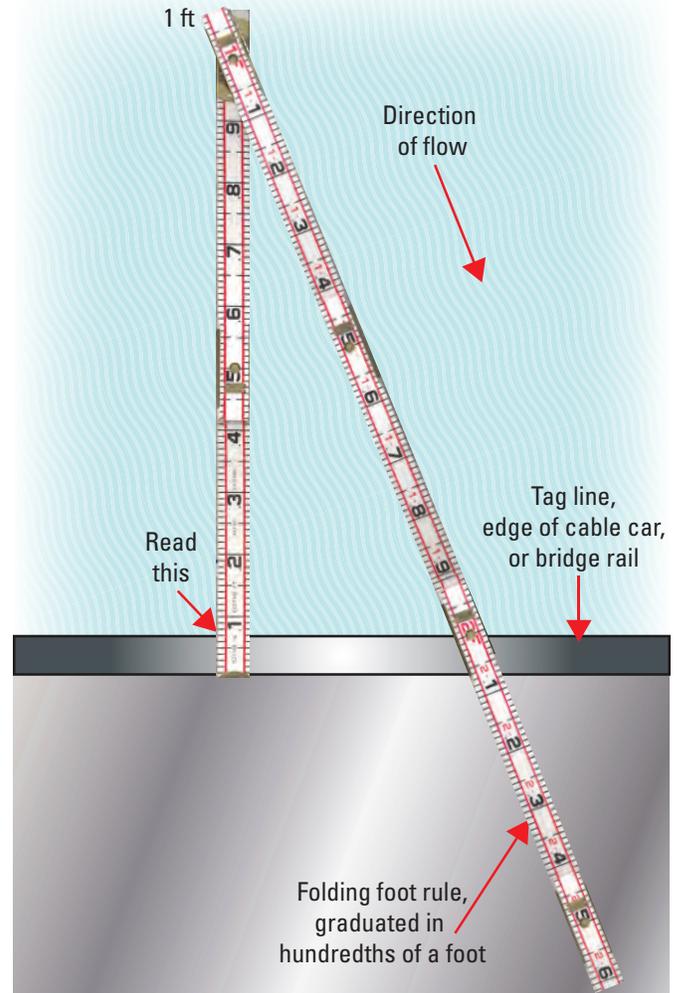


Figure 16. Measurement of horizontal angle with a folding rule.

stream. Therefore, whenever it is suspected that the direction of flow is variable at different depths, other means than those already mentioned must be used to determine the direction of flow. One such method is to use a rigid rod or pole, with a vane attached to the bottom, and an indicator parallel to the vane attached to the top. Another method is to use a sounding weight with a compass and remote readout, as described in the equipment section of this chapter. If the variation of the direction of flow in the vertical is not great, then an average value of the cosine of the angle may be used for computing the component mean velocity for the vertical. However, if the variation is considerable, then you may need to subdivide the vertical and make separate computations for each subdivision. This may require additional measurements of velocity in the vertical.

If available, an ADCP from a moving boat can be used to quickly discern multidirectional flow in the vertical and across the selected cross-section. In a tidal affected reach, an ADCP is the preferred method of measuring discharge because of its use in the measurement of three dimensional velocity through most of the water column.

Current-Meter Measurements by Wading

Current-meter measurements by wading are preferred, if conditions permit. Wading measurements offer the advantage over measurements from bridges and cableways because the hydrographer can usually choose the best of several available cross sections for the measurement. Figure 17 shows a wading measurement being made with a top-setting rod.

Use the type AA, pygmy, or ADV meter for wading measurements. Table 6 lists the type of meter and velocity method to use for wading measurements at various depths.

If a type AA meter is being used in a cross section where most of the depths are greater than 1.5 ft, do not change to the pygmy meter for a few depths less than 1.5 ft or vice versa. The Price AA meter is not recommended for depths of 1.0 ft or less because the registration of the meter is affected by its



Figure 17. Wading measurement using a top-setting rod.

Table 6. Current meter and velocity-measurement method for various depths.

Depth, in feet	Current meter	Velocity method
2.5 and greater	Price Type AA	0.2 and 0.8
1.5 - 2.5	Price Type AA	0.6
0.3 - 1.5	Price Pygmy	0.6
1.5 and greater	Price Pygmy	0.2 and 0.8
0.3 - 1.5	ADV	0.6
1.5 and greater	ADV	0.2 and 0.8

proximity to the water surface and to the streambed. However, it can be used at depths as shallow as 0.5 ft to avoid changing meters if only a few verticals of this depth are required. The type AA meter or the pygmy meter should not be used in velocities less than 0.2 ft/s unless it is absolutely necessary.

It is no longer recommended to use coefficients given by Pierce (1941) for the performance of current meters in water of shallow depth and low velocities.

When natural conditions for measuring are in the range considered undependable, modify the measuring cross section, if practical, to provide acceptable conditions. Often it is possible in small streams to build dikes to cut off dead water and shallow flows in a cross section, or to improve the cross section by removing the rocks and debris within the section and from the reach of stream immediately upstream from it. After modifying a cross section, allow the flow to stabilize before starting the discharge measurement.

Stand in a position that least affects the velocity of the water passing the current meter by facing the bank, with the water flowing against the side of the leg. Holding the wading rod at the tag line, stand from 1 to 3 in. downstream from the tag line and 18 in. or more from the wading rod. Avoid standing in the water if feet and legs would occupy a considerable percentage of the cross section of a narrow stream. In small streams where the width permits, stand on a plank or other support above the water rather than in the water. Velocity bias caused by effects of the hydrographer's position can be significant. Observance of these conditions is important while using mechanical meters, ADVs, and any wading measurement where an obstacle could interfere with the natural flow conditions of the stream.

When using a Price meter, keep the wading rod in a vertical position and the meter parallel to the direction of flow while observing the velocity. If the flow is not at right angles to the tag line, measure the angle coefficient carefully. When using an ADV or other instrument that can measure the x component velocity, the instrument should be aligned more precisely with the tag line. See the discussion of FlowTracker use and flow angles in the "Measurement of Velocity" section of this chapter.

During measurements of streams with shifting beds, the scoured depressions left by the hydrographer's feet can affect soundings or velocities. Generally, place the meter ahead of and upstream from the hydrographer's body and feet. Record an accurate description of streambed and water-surface configuration each time a discharge measurement is made in a sand-channel stream.

For discharge measurements of flow too small to measure with a current meter, use a volumetric method, Parshall flume, or weir plate. Those methods are described in subsequent sections of this chapter.

Current-Meter Measurements From Cableways

The Price type-AA current meter is generally used in conjunction with sounding weights and a sounding reel when measuring discharge from a cableway, although in recent years, using an ADCP mounted to a tethered craft has become much more widespread. Stationing (for width measurements) is usually determined from marks painted on the cableway. The velocity is measured by setting the meter at the proper position in the vertical, as indicated in table 7. Table 7 is designed so that no velocity observations will be made with the meter closer than 0.5 ft to the water surface. In the zone from the water surface to a depth of 0.5 ft, the current meter is known to give erratic results.

One problem found while measuring velocities from a cableway is that the movement of the cable car from one station to the next causes the car to oscillate for a short time after

coming to a stop. Wait until this oscillation has decreased to a negligible amount before counting the revolutions.

By using a method of tagging the sounding cable at convenient intervals with streamers of different-colored binding tapes, each colored streamer being a known distance above the current-meter rotor (known as using tags), the meter can be kept under water at all times to prevent it from freezing in cold air. Tags are also used in measurements of deep, swift streams. See the section of this chapter on “Measurement of depth.”

If large amounts of debris are flowing in the stream, raise the meter up to the cable car several times during the measurement to be certain the pivot and rotor of the meter are free of debris. However, keep the meter in the water during the measurement if the air temperature is considerably below freezing.

During floods, there is always a danger of catching a submerged or floating object, such as a tree or log, which can endanger the sounding equipment, meter, and most importantly, the hydrographer. Always be sure that the sounding cable has been installed on the sounding reel, according to the breaking loads specified in table 8. This assures that the sounding cable will break when it reaches its end, thereby preventing a potentially serious accident where the cable car and hydrographer could be spilled into the stream. Also, for added safety, always carry a pair of lineman’s side-cutter pliers while making measurements from a cableway. If the sounding cable becomes hopelessly hung and does not break, as it should, cut the sounding line to ensure safety. Sometimes the cable car can be pulled to the edge of the water and the debris can be released.

When measurements are made from cableways where the stream is deep and swift, measure the angle that the meter suspension cable makes with the vertical due to the drag. The vertical angle, measured by protractor, is needed to correct the soundings to obtain the actual vertical depth, as described in the section on “Depth corrections for downstream drift of current meter and weight.”

Table 7. Velocity-measurement method for various suspensions and depths.

Suspension	Minimum depth, in feet	
	0.6 method	0.2 and 0.8 method
15 C .5 ¹ , 30 C .5	1.2	2.5
50 C .55	1.4	2.8
50 C .9	2.2	4.5
75 C 1.0, 100 C 1.0, 150 C 1.0	2.5	5.0
200 C 1.5, 300 C 1.5	3.8 ²	7.5

¹15 pound Columbus-type weight, 0.5 above channel bed.

²Use 0.2 method for depths 2.5 to 3.7 feet with appropriate coefficient (for example, 0.87 or 0.88).

Table 8. Breaking loads for Ellsworth stranded cable.

Sounding cable	Diameter, in inches	Total number of strands	Rated total breaking load, in pounds	Recommended breaking load, in pounds	Number of strands to cut	Number of strands to remain
Ellsworth 0.084	0.084	36	500	250	15	21
Ellsworth 0.100	0.100	30	1,000	500	15	15
Ellsworth 0.125	0.125	30	1,500	500	20	10

Current-Meter Measurements From Bridges

When a stream cannot be waded, a bridge may be used to obtain current-meter measurements. Many measuring sections under bridges are satisfactory for current-meter measurements, but cableway sections are usually better because they provide an unobstructed reach of the channel. In addition, cableways usually have no bridges constricting the free flow of the stream in the measuring reach.

No set rule can be given for choosing between the upstream or downstream side of the bridge while making a discharge measurement. The advantages of using the upstream side of the bridge are the following:

- Hydraulic characteristics at the upstream side of bridge openings usually are more favorable. Flow is usually smoother and there is less turbulence than at the downstream side of the bridge.
- Approaching drift can be seen and be more easily avoided.
- The streambed at the upstream side of the bridge is not likely to scour as much as at the downstream side.

The advantages of using the downstream side of the bridge are:

- Vertical angles are more easily measured because the sounding line will move away from the bridge.
- The flow lines of the stream may be straightened out by passing through a bridge opening with piers.

Using the upstream side or the downstream side of a bridge for a current-meter or ADCP measurement should be decided based on circumstances for each bridge. Consider the factors mentioned above and the physical conditions at the bridge, such as location of the walkway, traffic hazards, and accumulation of trash on piles and piers.

For an ADCP measurement with a tethered craft, unless a special rigid support for deployment or bank-operated cableway has been developed for the upstream side of the bridge, the downstream side of the bridge is usually where the ADCP is most conveniently deployed. Bridge piers can cause excessive turbulence during high streamflow, especially if debris accumulates on the piers and/or the piers are skewed to the flow. The effect of bridge-pier-induced turbulence may be reduced when deploying an ADCP from the downstream side of the bridge by lengthening the tether to increase the distance between the bridge and the tethered boat. Close attention should be paid to the cross section to ensure that no large eddies that could cause flow to be nonhomogeneous are present. Possible alternatives to measuring off the downstream side of the bridges include using a bank-operated cableway, a rigid extension that allows the hydrographer to deploy from the upstream side of the bridge, or having personnel on each bank hold a rope or cord attached to the platform to pull the tethered boat back and forth across the river.

For a mechanical current meter measurement, use either a handline, or a sounding reel supported by a bridge board or a portable crane, to suspend the current meter and sounding weight from bridges. Depth measurements should be made as described in the section entitled "Measurement of depth." Measure the velocity by setting the meter at the position in the vertical as indicated in table 7. Keep equipment several feet from piers and abutments if velocities are high. Estimate the depth and velocity next to the pier or abutment on the basis of the observations at the nearest vertical.

If there are piers in the cross section, it is usually necessary to use more than 25 to 30 partial sections to get results as reliable as those from a similar section without piers. Piers will often cause horizontal angles that must be carefully measured. Piers also cause rapid changes in the horizontal-velocity distribution in the section.

Whether or not to exclude the area of a bridge pier from the area of the measurement cross section depends primarily on the relative locations of the measurement section and the end of the pier. If measurements are made from the upstream side of the bridge, it is the relative location of the upstream end (nose) of the pier that is relevant; for measurements made from the downstream side, it is the location of the downstream end (tail) of the pier that is relevant. If any part of the pier extends into the measurement cross section, the area of the pier is excluded. Bridges quite commonly have cantilevered walkways from which discharge measurements are made. In these cases, the measurement cross section lies beyond the end of the pier (upstream from the pier nose or downstream from the pier tail, depending on which side of the bridge is used). In that situation, it is the position and direction of the streamlines that determines whether or not the pier area is to be excluded. If the stationing of the sides of the pier when projected to the measurement cross section was not already done, the hydrographer does it at this point. If there is negligible or no downstream flow in that width interval (pier subsection), then the pier is excluded. That is, if only stagnation and (or) eddying exists upstream from the pier nose or downstream from the pier tail, whichever is relevant, the area of the pier is excluded. If there is substantial downstream flow in the pier subsection, the area of the pier is included in the area of the measurement cross section. In that circumstance, the horizontal angles of the streamlines in and near the pier subsection will usually be quite large.

Footbridges are sometimes used for measuring canals, tailraces, and small streams. Rod suspension can be used from many footbridges. The procedure for determining depth in low velocities is the same as for wading measurements. For higher velocities, obtain the depth by the difference in readings at an index point on the bridge when the base plate of the rod is at the water surface and on the streambed. Measuring the depth in this manner will eliminate errors caused by the water piling up on the upstream face of the rod. ADCP tethered boats, handlines, bridge cranes, and bridge boards are also used from footbridges.

The handline can be disconnected from the headphone wire and passed around a truss member with the sounding

weight on the bottom. This eliminates the need for raising the weight and meter to the bridge each time a move is made from one vertical to another; it is the principal advantage of a handline.

Safety is a primary consideration when measuring discharge from bridges. High-speed traffic can present a major safety hazard; in fact, it is no longer permissible to make discharge measurements from some Interstate route bridges without special permission. Observe all safety precautions, such as the use of traffic cones, traffic signs, and flag persons, that are prescribed in the USGS Water Science Center's flood plan and safety plan.

Observe the same safety precautions regarding the snagging of debris, such as floating or submerged trees or logs, as described above for cableways.

Current-Meter Measurements From Ice Cover

Discharge measurements under ice cover, as shown in figure 18, are made under the most severe conditions, but are extremely important because a large part of the discharge record during a winter period may depend on one measurement. In recent years ADCPs and ADVs have increasingly been used to make measurements from ice cover.

Select the possible locations of the cross section to be used for measurement from ice cover during the open-water season when channel conditions can be evaluated. Commonly, the most desirable measurement section will be just upstream from a riffle because slush ice that collects under the ice cover is usually thickest at the upstream end of the pools created by riffles.

The equipment used for cutting or drilling the holes in the ice is described in a previous section of this chapter.

Never underestimate the danger of working on ice-covered streams. When crossing, test the strength of the ice with solid blows using a sharp ice chisel. Ice thickness may be irregular, especially late in the season when a thick snow cover may act as an insulator. Water just above freezing can slowly melt the underside of the ice, creating thin spots. Ice that is bridged above the water may be thick but still be weak.

Cut the first three holes in the selected cross section at the quarter points to detect the presence of slush ice or poor distribution of the flow in the measuring section. If poor conditions are found, investigate other sections to find one that is free of slush ice and that has good distribution of flow. After finding a suitable cross section, make at least 20 holes in the ice for a current-meter measurement. Space the holes so that no partial section contains more than 10 percent of the total discharge. On narrow streams, it may be simpler to remove all of the ice in the cross section.

The effective depth of the water, as shown in figure 19, is the total depth of water minus the distance from the water surface to the bottom of the ice. The vertical pulsation of water

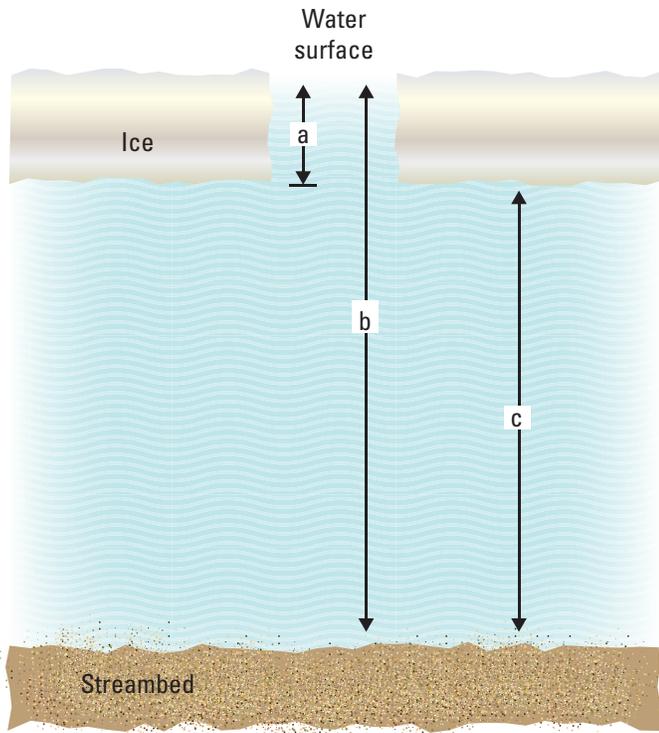


Figure 18. A, Ice drill being used to cut holes and B, ice rod being used to support current meter for a discharge measurement.

in the holes in the ice sometimes causes difficulty in determining the depths. The total depth of water is usually measured with an ice rod or with a sounding weight and reel, depending on the depth.

Measure the distance from the water surface to the bottom of the ice with an ice-measuring stick. Do not use the ice-measuring stick if there is slush under the solid ice at a hole. In order to find the depth at which the slush ice ends, suspend the current meter below the slush ice with the meter rotor turning freely. Raise the meter slowly until the rotor stops. This point is used as the depth of the interface between water and slush. After the effective depth of the water has been determined, compute the proper position of the meter in the vertical as shown in figure 19.

Use the Price winter Water Survey of Canada (WSCan) current meter yoke, with a polymer rotor, under ice cover when slush ice is present because the cups are solid and cannot become filled with slush ice; this is what happens with the cups of the regular Price meter. For situations where slush ice is not present, use the Price winter WSCan current meter yoke



a = Water surface to bottom of ice
 b = Total depth of water
 c = Effective depth (c=b-a)

0.2-depth setting = a + 0.2c
 0.8-depth setting = b - 0.2c
 0.6-depth setting = b - 0.4c

Figure 19. Method of computing meter settings for measurements under ice cover.

with regular Price metal cups. The old-style vane ice meter is no longer recommended, primarily because of its poor performance in slow velocities.

The velocity distribution under ice cover, when the water is in contact with the underside of the ice, is similar to that in a pipe, with a lower velocity nearer the underside of the ice. This is illustrated in figure 20. Use the 0.2- and 0.8-depth method for effective depths of 2.5 ft or greater, and the 0.6-depth method for effective depths of less than 2.5 ft. Define two vertical-velocity curves while making ice measurements to determine whether any coefficients are necessary to convert the velocity (obtained by the 0.2- and 0.8-depth method or the 0.6-depth method) to the mean velocity. Normally, the average of the velocities obtained by the 0.2- and 0.8-depth method gives the mean velocity, but a coefficient of about 0.92 usually is applicable to the velocity obtained by the 0.6-depth method.

When measuring the velocity, keep the meter as far upstream as possible to avoid any effect that the vertical pulsation of water in the hole might have on the meter. Eliminate as much as possible the exposure of the meter to the cold air during the measurement. The meter must be free of ice when the velocity is being measured.

If there is partial ice cover at a cross section, use the procedure described above where there is ice cover, and use open-water methods elsewhere.

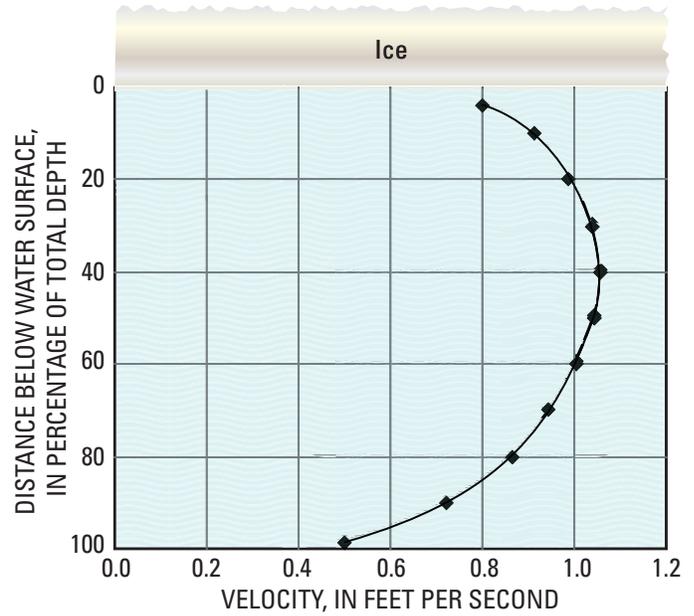


Figure 20. Typical vertical-velocity curve under ice cover.

DISCHARGE MEASUREMENT NOTES—ICE COVER
 FRIO River, at COLD HARBOR, ME
 Creek, near METER = V-587

REW Dist. from initial point	Width	Total depth of water	W.S. to bot. ice	Effective depth	Depth of meter below water surface	Revol- utions	Time in seconds	VELOCITY		Area	Discharge
								At point	Mean in vertical		
1315											
24	3	0						0	0	0	
30	6	2.6	1.6	1.0	2.2	10	47	.49	.45	6.0	2.7
36	6	3.6	1.8	1.8	2.9	15	49	.69	.63	10.8	6.8
42	5	4.3	2.0	2.3	3.4	15	44	.77	.71	11.5	8.2
46	4	4.5	1.8	2.7	2.3	20	43	1.04	.84	10.8	9.1
50	4	4.7	1.7	3.0	2.3	20	40	1.12	.90	12.0	10.8
54	4	4.6	1.7	2.9	2.3	25	49	1.14	.94	11.6	10.9
1325					4.0	15	46	.74			
58	4	4.9	1.6	3.3	2.3	20	40	1.12	.90	13.2	11.9
62	4	4.8	1.6	3.2	2.2	25	48	1.17	.96	12.8	12.3
66	3.5	5.0	1.5	3.5	2.2	25	44	1.27	1.04	12.2	12.7
69	3	5.3	1.6	3.7	2.3	25	40	1.40	1.12	11.1	12.4
72	3	5.1	1.5	3.6	2.2	25	41	1.36	1.12	10.8	12.1
1335					4.4	20	51	.88			
	495									122.8	109.9

Figure 21. Part of note sheet for discharge measurement under ice cover.

A sample sheet of discharge-measurement notes under ice cover is shown in figure 21. In this measurement, the vertical-velocity curves indicate that the 0.2- and 0.8-depth method gives the mean velocity and that the 0.6-depth method requires a coefficient of 0.92.

Current-meter measurements under ice cover are frequently made with a special winter-style sounding rod, ADV or ADCP, as described in this chapter. When depths are too deep for rod suspension, use an equipment assembly mounted on runners, such as shown in figure 22. For winter conditions, the 30-pound C-type weights should be used with a special, collapsible hanger assembly (shown in figure 22) that can be passed through an 8-in. hole in the ice. A handline can also be used for making ice measurements.

Where it is impractical to use a powered ice drill, use ice chisels to cut the holes. Ice chisels are usually 4- or 4.5-ft long and weigh about 12 pounds. Use the ice chisel when first crossing an ice-covered stream to determine whether the ice is strong enough to support the hydrographer. If a solid blow of the chisel blade does not penetrate the ice, it is safe to walk on, providing the ice is in contact with the water.

Some hydrographers supplement the ice chisel with a Swedish ice auger. The cutting blade of this auger is a spade-like tool of hardened steel that can cut a hole 6 to 8 in. in diameter by turning a brace-like arrangement on top of the shaft.

After the hole is made in the ice, water will be forced up, owing to the water being under pressure from the weight of the ice. In order to determine the effective depth of the stream, use ice-measuring sticks to measure the distance from the water surface to the bottom of the ice. Measuring this distance is done using a bar about 4 ft long, made of strap steel or wood, graduated in feet and tenths of a foot and having an L-shaped projection at the lower end. Hold the horizontal part of the L on the underside of the ice and read the depth to that point at the water surface on the graduated part of the stick. The horizontal part of the L is at least 4 in. long so that it may extend beyond any irregularities on the underside of the ice.



Figure 22. Collapsible hanger assembly for used with 30- and 50-pound C-type weights, for measurements under ice (A, in measurement position and B, collapsed).

Current-Meter Measurements From Stationary Boats

Discharge measurements are made from boats where no cableways or suitable bridges are available and where the stream is too deep to wade, although ADCP discharge measurements from a moving boat, now a USGS standard operating procedure, have largely replaced this method. Personal safety is the limiting factor in the use of boats on streams having high velocity of flow.

For boat measurements whether using a mechanical meter or an ADCP, select a cross section that has attributes similar to those described in the previous section “Site selection,” except for those listed in items concerning depth and velocity. There is no need to consider depth in a boat measurement because if the stream is too shallow to float a boat, the stream can usually be waded. Velocity, however, is an important concern. If velocities are too slow, mechanical current meter registration may be affected by an oscillatory movement of the boat, in which the boat (even though fastened to a tag line) moves upstream and downstream as a result of wind action. Vertical movement of the boat as a result of wave action may also affect a vertical-axis current meter. If velocities are too fast, it becomes difficult to string a tag line across the stream.

If it is feasible to use a tag line in making a boat measurement, string it at the measuring section by unreeling the line as the boat moves across the stream. After a tag line without a brake has been stretched across the stream, take up the slack by means of a block and tackle attached to the reel and to an anchored support on the bank. If there is traffic on the river, one person must be stationed on the bank to lower and raise the tag line to allow the river traffic to pass. Place streamers on the tag line so that it is visible to boat pilots. If there is a continual flow of traffic on the river, or if the width of the river is too great to stretch a tag line, other means will be needed to

position the boat. Night measurements by boat are not recommended because of the safety concerns.

When no tag line is used, the boat can be kept in the cross section by lining it up with flags positioned on each end of the cross section, as illustrated in figure 23. Flags on one bank would suffice but it is better to have them on both banks. Determine the position of the boat in the cross section by using a transit or total station on the shore and a stadia rod held in the boat. Another method of determining the position of the boat is by setting a transit or total station on one bank a convenient, known distance from and at right angles to the cross-section line. The position of the boat is determined by measuring the angle α to the boat, measuring the distance CE , and computing the distance MC as shown in figure 24. A third method of determining the position of the boat is done with a sextant read from the boat. Position a flag on the cross-section line and another at a known distance perpendicular to the line. The boat position can be computed by measuring the angle β with the sextant, as shown in figure 24. Boat position can also be determined by using a global positioning system with differential corrections (DGPS). This method is especially useful on wide streams and in flood plains where other methods of determining boat position are not applicable. Unless anchoring is more convenient, the motor must hold the boat stationary while readings are being taken.

Do not take boat measurements at velocities less than 1 ft/s when the boat is subject to wave action. The up-and-down movement of the boat (and the meter) seriously affects the velocity observations. If the maximum depth in the cross section is less than 10 ft and the velocity is low, the hydrographer can use a rod for measuring the depth and for supporting the current meter. For greater depths and velocities, use a cable suspension with a reel and sounding weight. The procedure for measuring from a stationary boat using the boat boom and crosspiece is the same as that for measuring from a bridge or a cableway, as described in previous sections of this chapter.

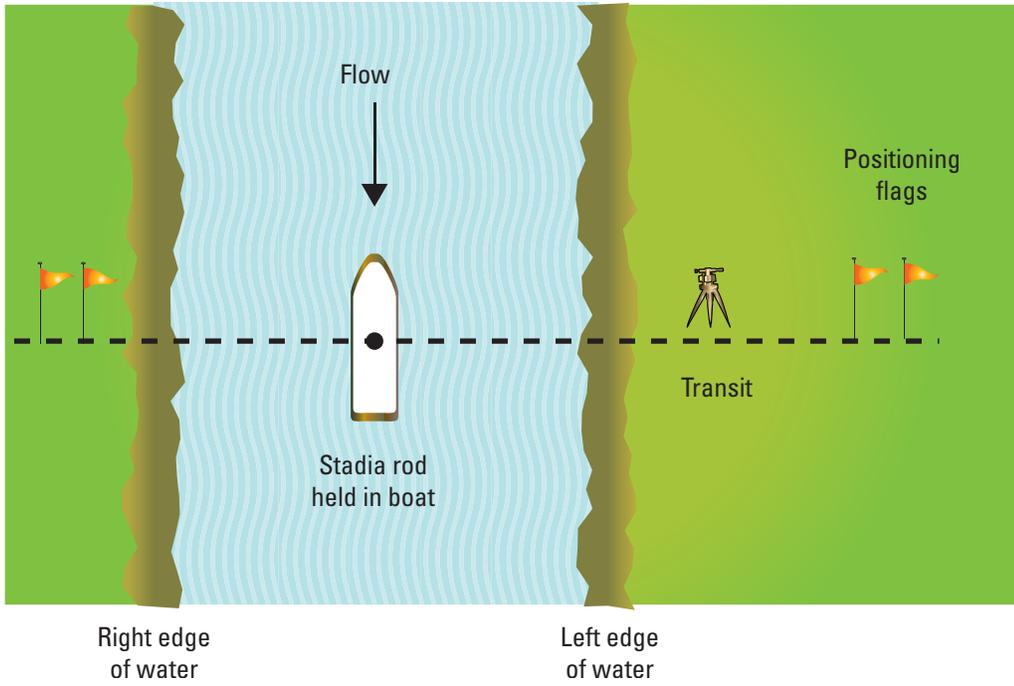


Figure 23. Determining the position in a cross section using the stadia method.

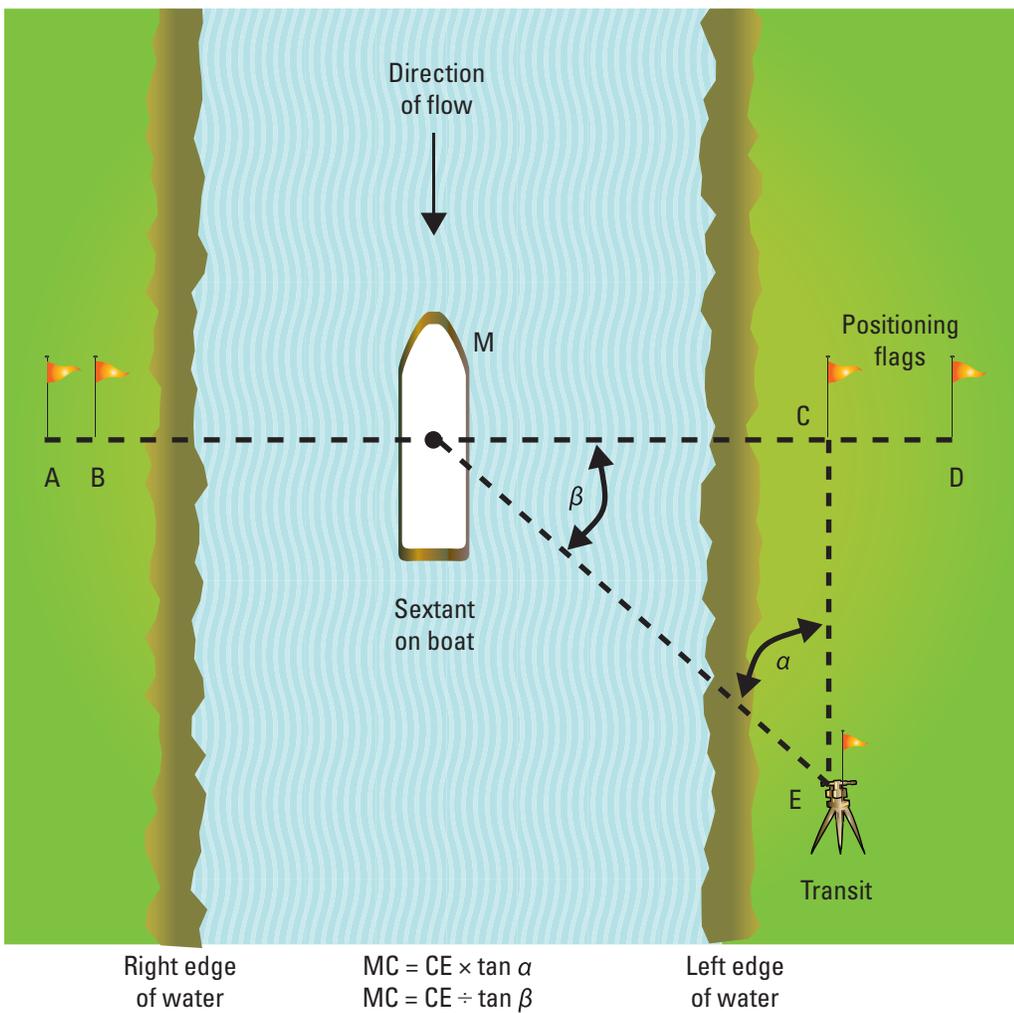


Figure 24. Determining the position in a cross section using the angular method.

Moving-Boat Measurements of Discharge

On large streams and estuaries, the midsection methods of measuring discharge are frequently impractical and involve costly and tedious procedures. There may be no facilities at remote sites. Where facilities do exist, they may be inundated or inaccessible during floods. At some sites, unsteady flow conditions require that measurements be made as rapidly as possible. Measurements on tide-affected rivers must not only be made frequently, but continually, throughout a tidal cycle. The moving-boat technique is a method of quickly measuring a large stream. It requires no fixed facilities, and it lends itself to the use of alternate sites if conditions make this applicable. Brief descriptions of three moving-boat methods are given in the following sections. It must be stated here that these methods have been almost entirely replaced by the use of ADCP discharge measurements. Details of ADCP setup and use can be found in Mueller and Wagner (2009) and subsequent section of this chapter discussing the moving boat method using an ADCP.

Manual Method, Using a Mechanical Current Meter

Smoot and Novak (1968) describe the manual moving-boat technique in detail. It is similar to the mechanical current-meter measurement in that the velocity-area approach is used to determine the discharge. The total discharge is the summation of the products of the partial areas of the stream cross section and their respective average velocities. During the traverse of a stream by boat, a sonic sounder records the geometry of the cross section, and a continuously operating current meter senses the combined stream and boat velocities.

The current meter used for a moving-boat measurement is a component propeller type, such as the Ott current meter, with a custom body made for mounting on the leading edge of a vane. The current meter and vane assembly are attached to a vertical rod and bearing assembly that allows them to rotate freely. An angle indicator is located at the top of the rod, which indicates the crab angle.

It usually takes three people to make a moving-boat measurement: one to operate the boat, one to make crab-angle observations, and one to take notes. The note keeper is responsible for recording the crab-angle observations and the current-meter pulses. Depths are recorded automatically on the sonic-sounder chart. Special computations and conversions, which are somewhat tedious, are required to determine stationing and normal mean velocities for each vertical. Discharge can then be computed similar to a standard velocity-area discharge measurement. Experience has shown that measurements obtained by the moving-boat technique compare within 5 percent of measurements obtained by conventional means.

Automatic Computerized Method, Using a Mechanical Current Meter

The automatic computerized moving-boat method is the same basic procedure as the manual moving-boat method described above, except that all readings of depth, velocity, crab angles, and boat position are automatically fed into an onboard computer. A substantial difference is that the automated moving-boat method requires only two crew members—a boat operator and an instrument operator. The manual method requires three crew members.

The automated method requires an electronic compass that provides automatic input of the crab angle. The current meter and depth sounder likewise provide automatic input of pulse rates and depth, respectively. The computer is programmed to make the conversions and computations that would normally be made manually, thereby speeding up the computation process and virtually eliminating arithmetic errors. A computed measurement is available immediately after completion of the data collection.

Moving-Boat Method, Using an ADCP

ADCPs can be used to measure unsteady, bidirectional, and other flows with nonlogarithmic velocity distributions—problems hydrologists have faced for decades. ADCPs are called profilers because they provide measurements of velocity throughout the water column. The ADCP divides the water column into depth cells (also referred to by some software and references as “bins”) and reports a velocity for each depth cell; however, an ADCP cannot measure velocities near the water surface or near the bed. The length of the unmeasured zone at the water surface is a function of the draft of the instrument deployment, the effect of the transducer mechanics, and the flow disturbance around the instrument. The length of the unmeasured zone near the streambed is due to side-lobe interference, which is a function of the mechanics of transducers and the slant angle of the beams. The ADCP must be deployed below the water surface; therefore, it cannot measure the water velocity above the transducers.

Although ADCPs have no moving parts and typically require no calibration, the instruments and associated software and firmware are complex. Using quality-assurance procedures defined by Oberg and others (2005) and Mueller and Wagner (2009) will help identify potential instrument problems.

ADCPs can be mounted on either side of manned boats, off the bow, or in a well through the hull. A tethered boat can be defined as a small boat (usually less than 6.5 ft long) attached to a rope, or tether, that can be deployed from a bridge, a fixed cableway, a moving boat, or a temporary or permanent bank-operated cableway. The tethered boat should be equipped with an ADCP mount that meets all of the specifications for manned boats. Unmanned, remote-control ADCP boats are also used and allow the deployment of ADCPs where deployment with a manned boat or tethered boat may not be feasible or ideal. Similar to (but smaller than) a manned boat,

a remote-control boat has self-contained motors and a remote-control system for maneuvering the boat across the river.

The procedures for predeployment preparation, field data collection, and processing of collected data are discussed in detail by Mueller and Wagner (2009). A detailed description of how an ADCP measures velocity and computes discharge and additional details on selected topics are presented in the appendices (Mueller and Wagner, 2009).

Networks of Current Meters

In the past, occasional special measurements made by USGS hydrographers have required simultaneous velocities at several points in a cross section, distributed either laterally or vertically. For example, it may be necessary to measure a vertical-velocity profile quickly in unsteady flows and to check it frequently in order to determine the changes in shape of the vertical profile, as well as the rates of these changes. In another example, for the measurement of tide-affected streams, it is desirable to measure the total discharge continuously during at least a full tidal cycle (approximately 13 hours). The need for so many simultaneous velocity determinations (one at each vertical in the cross section) for so long a period could be an expensive and laborious process using conventional techniques of discharge measurement.

A grouping of 21 current meters and special instrumentation has been devised in the past by the USGS to facilitate measurements of the types just described. The 21 meters are connected together so that the spacing between any two adjacent meters can vary up to 200 ft. In using this method, each meter should be uniformly calibrated and have sufficient handline cable to be suspended vertically from a bridge as much as 200 ft. Revolutions of the rotors are recorded by electronic counters that are grouped compactly in one box at the center of the bank of meters. The operator, by flipping one switch, starts all 21 counters simultaneously, and after an interval of several minutes, stops all counters. The indicated number of revolutions for the elapsed time interval is converted to a velocity for each meter. The distance between meters is known, and a record of stage is maintained to evaluate depth. Prior information at the site is obtained to convert point velocities in the verticals to mean velocities in those verticals. All of the information necessary to compute discharge in the cross section is available, and is tabulated for easy conversion to discharge. If possible a concurrent ADCP discharge measurement should be completed in close proximity and time to this measurement to corroborate the results.

Discharge Measurement of Deep, Swift Streams With a Mechanical Current Meter

Discharge measurements of deep, swift streams with a mechanical current meter usually present no serious problems when adequate sounding weights are used and when floating drift or ice is not excessive. Normal procedures must sometimes be altered, however, when measuring these streams. The four most common circumstances are the following:

1. It is possible to sound, but the weight and meter drift downstream.
2. It is not possible to sound, but a standard cross section is available.
3. It is not possible to sound, and a standard cross section is not available.
4. It is not possible to put the weight and meter in the water.

Procedures are described below for use during measurements made under each of these conditions. Use procedures for items 2, 3, and 4 where there is a stable cross section. The procedure for unstable channels must be determined by conditions at each location.

Possible To Sound, but Weight and Meter Drift Downstream

For some streams, it may be possible to sound the streambed, but because of the force of high velocities, the weight and meter are carried downstream. This may be a condition for only a few verticals near the center of the stream, or it may affect many of the verticals. Make corrections to the observed depths and meter settings to account for the downstream drift. These corrections are commonly referred to as “vertical angle corrections.” The procedure for computing vertical angle corrections is described in a previous section of this chapter entitled “Depth corrections for downstream drift of current meter and weight.” The corrections can be computed manually, or they may be computed automatically through the use of an electronic notebook or a PDA.

Not Possible To Sound, but Standard Cross Section Available

When it is not possible to sound the streambed, use a standard cross section from previous measurements at the bridge or cableway for determining depth. Such a cross section is useful only if all discharge measurements use the same permanent initial point for the stationing of verticals across the width of the stream. There should also be an outside reference gage or reference point on the bank or bridge to which the water-surface elevation at the measurement cross section

may be referred. If these conditions are met, use the following procedure to make a discharge measurement:

1. Determine the depths from the standard cross section, based on the water-surface elevation.
2. Measure the velocity at 0.2 of the depth at each vertical.
3. Compute the measurement in the normal manner using the measured 0.2-depth velocities as though they were the mean velocities in the vertical. Apply horizontal-angle corrections, if necessary. Use depths as determined in step 1 above.
4. Determine the coefficient to adjust the 0.2-depth velocity to the mean velocity on the basis of previous measurements at the site by the two-point method. See a previous section of this chapter entitled “Two-tenths-depth method.”
5. Apply the coefficient from step 4 to the computed discharge from step 3.

Not Possible To Sound, and Standard Cross Section Not Available

When it is not possible to sound the streambed and a standard cross section is not available, use the following procedure:

1. Reference the water-surface elevation before and after the measurement to an elevation reference point on a bridge, on a driven stake, or on a tree at the water’s edge. It is assumed here that no outside reference gage is available at the measurement cross section.
2. Estimate the depth and observe the velocity at 0.2 of the estimated depth. The meter should be at least 2.0 ft below the water surface. In the notes, record the actual depth the meter was placed below the water surface. If an estimate of the depth is impossible, place the meter 2.0 ft below the water surface and observe the velocity at that point.
3. Make a complete measurement, including some vertical-velocity curves, at a lower stage when you can sound the streambed.
4. Use the complete measurement and difference in stage between the two measurements to determine the cross section of the first measurement. To determine whether the streambed has shifted, compare the cross section with one taken for a previous measurement at that site.
5. Use vertical-velocity curves, or the relation between mean velocity and 0.2-depth velocity, to adjust the velocities

observed in step 2 to mean velocity. Apply horizontal-angle corrections as necessary.

6. Compute the measurement in the normal manner using the depths from step 4 and the velocities from step 5.

Not Possible To Put the Weight and Meter in Water

If it is impossible to put the sounding weight and mechanical current meter in the water because of high velocities and (or) floating drift, use the following procedure:

1. Obtain depths at the measurement verticals from a standard cross section, if one is available. If a standard cross section is not available, determine depths by the method explained above in the section “Not possible to sound, and standard cross section not available.”
2. Measure velocities and compute discharge using an ADCP.
3. Measure surface velocities by timing floating drift, or by using an optical or other approved noncontact flowmeter.
4. Compute the measurement in the normal manner, using the surface velocities as though they were the mean velocities in the vertical, and using the depths from step 1.
5. Apply the appropriate velocity coefficient to the discharge computed in step 3. Use a coefficient of 0.86 for a natural channel and 0.90 for an artificial channel.

The optical current-meter and ADCP measurement procedures are described in previous sections of this chapter and by Mueller and Wagner (2009). The optical current meter is portable, battery operated, and requires no great skill for quick and accurate readings of the surface rate of flow. The meter is not immersed, so it does not disturb the flow, and it is in no danger of damage from floating debris or ice. In many cases, the ADCP has become the most efficient alternative to the mechanical current meter where velocities are too great; however, the ADCP also has limitations. See the previous sections of this chapter for information on velocity, depth, turbidity, and other site-condition limitations of the ADCP.

Keep in mind that just after the crest, the amount of floating drift or ice is usually greatly reduced, and it may be possible to obtain velocity observations with a current meter. These observations can help define the velocity coefficient mentioned in step 5 above.

Recording Field Notes

Field notes for a discharge measurement may be recorded on standard paper note sheets (for example, USGS Forms 9-275-F, 9-275-I, and other special field forms). With the ADCP discharge measurement, the software attached to each instrument contains digital forms for the recording of some of the field data. The USGS has developed a paper form for recording field data observed during an ADCP discharge measurement (fig. 2D). With a current-meter discharge measurement, field forms can be recorded using an electronic notebook, such as the Aquacalc or a Personal Digital Assistant (PDA). With an ADV measurement, there are special field forms to accommodate its specifications and details. These methods are described in more detail in subsequent paragraphs in this section. The SWAMI program with a PDA (commonly used by the USGS) can be used to record discharge measurements, inspections, differential level surveys, and other field measurements. SWAMI has an interface with the National Water Information System (NWIS), so measurements are easily uploaded to NWIS (fig. 2C).

Standard Paper Note Keeping for a Mechanical Current-Meter Discharge Measurement

Paper note sheets, as shown in figure 2A, are the traditional way to record the field observations for a mechanical current meter, ADV, or ADCP discharge measurement. Generally, for each discharge measurement, the hydrographer should record the following information, at a minimum, on the front sheet of the measurement notes (the information may vary, depending on the meter and method being used):

- Measurement number, who computed, and who checked the measurement;
- Downstream station identification number and station name (station name includes stream name and location, to correctly identify an established gaging station). For a miscellaneous measurement, record the stream name and exact location of site;
- Date of measurement and members of measurement party (initials and last name);
- Measured channel width, area, average velocity (computed as a ratio of the measured discharge/measured area), average gage height, and discharge;
- Vertical velocity method(s) of measurement, number of sections, and change in gage height during the discharge measurement;
- Measurement method coefficient, horizontal-angle coefficient, type of meter suspension (for example, rod, 100#C, and so forth) and whether tags were checked;
- Type of meter (for example, AA or pygmy), the current meter's serial number; and the elevation of the meter above the channel bottom;
- Meter rating used (for example, Standard Rating No. 2) and the most recent spin test results;
- Measurement percentage (after computed) from the existing stage-discharge rating, and the indicated shift in feet from that rating;
- GAGE READINGS: Do not erase inside this block on the front sheet. If an error is made, cross through the error and write the correct reading.
 - Start time measurement using 24-hour clock time, and record the time zone (that is, EST, CST, EDT, and so forth).
 - Record inside and outside gage, and also readings from recording devices (for example, data logger, graphic, and so forth).
 - Compute weighted mean gage height either by averaging readings, or if sufficient change in gage height occurred, by using methods for weighting gage height discussed in this chapter.
 - Compute gage-height correction caused by difference in true gage height (reference gage) and recorder or other gage that is reading incorrectly.
 - Record the correct mean gage height.
- Samples collected: Indicate type of water-quality measurements and samples [that is, water-quality, sediment, and (or) biological], and indicate if the measurements are documented on separate sheets (that is, water quality, aux./base gage, other);
- Indicate whether the rain gage (if applicable) was serviced/calibrated;
- Briefly describe the weather (for example, sunny, cloudy, rainy, cold, or other);
- Record the air temperature in degrees Celsius and the time of the reading;
- Record the water temperature in degrees Celsius and the time of the reading;
- Record the check bar reading (if a wire weight is present), time of the reading, and any adjustments in elevation made to the check bar.
- Indicate the type of measurement (wading, cable, ice boat, and so forth) and location of measurement relative to the gage (upstream, downstream, and so forth).
- Rate the measurement based on the hydrologic/hydraulic conditions in which the measurement was made [that is, excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent)].
- Flow: Document the hydraulic condition of the flow (steady, unsteady, where the flow was within the cross section, and so forth).
- Cross section: Geomorphologically describe the cross section (that is, sand, clay, cobble, and so forth), shape, presence of vegetation, and any other roughness affecting flow.

- Document if the gage is operating and whether the record was removed during this visit;
- Note the battery voltage and the cleaning of the orifice or intakes;
- If appropriate, indicate pressure readings of the nonsubmersible pressure transducer (that is tank, line, bubble-rate (bubbles/minute));
- Indicate if appropriate, readings of extreme indicators of high flow.
- Document the condition of the crest stage gage (CSG) and record the high water mark (HWM) if a reading is available on the CSG and the reference elevation.
- Record any other HWM obtained at the gage, if appropriate.
- Control conditions: Describe what and where the control of flow is for the gage pool (that is, gravel riffle about 80 ft downstream of the gage, and so forth).
- REMARKS: Use this space to document any unusual conditions in the gage reach that might affect the measurement, record, or other pertinent information regarding the accuracy of the discharge measurement and conditions that might affect the stage-discharge relation and document any observer reading or results of discussions with an observer.
- Measure the gage height of zero flow as many times a year as possible; record to the nearest 0.1 ft. Do this by recording the gage height at the gage at the time the gage height at zero flow is measured. Subtract the gage height from the depth of flow at the point the gage height at zero flow is measured and rate this measurement as good, fair, or poor.
- Fill in all items on the front sheet or mark with a dash after the measurement is completed and computed.

Mechanical Current-Meter Inside Notes

In the inside notes of a mechanical current-meter discharge measurement, identify the measurement starting point by either left edge of water or right edge of water (LEW or REW, respectively), when facing downstream, and record the time you started the measurement. If a significant change in stage is expected during the measurement, periodically record the time for intermediate verticals during the course of the measurement. If possible, synchronize this time with the recording interval of the digital recorder or data logger. Intermediate times are important because if there is any appreciable change in stage during the measurement, these recorded times are used to determine intermediate gage heights, which are then used to compute a weighted mean gage height for the measurement, as described in a subsequent section of this chapter. When the measurement is completed, record the time and the bank of the stream (LEW or REW) where the section ends.

Begin the measurement by recording the distance from the initial point to the edge of the water. Measure and record

the depth, and velocity (if any), at the edge of water. Compute the width using the midsection method described in a previous section of this chapter. Proceed across the measurement section by measuring and recording the distance of each vertical from the initial point; the depth at the vertical; the observation depths as 0.6, 0.2, 0.8, and so forth; the revolutions and time for each velocity observation; and the horizontal angle coefficient if different than 1.00.

Complete all computations required for the inside notes to determine the total width, area, and discharge. Transfer these values to the front sheet and complete other items on the measurement front sheet. The measurement computations should be made, and the note sheets completed, before the hydrographer leaves the gaging station.

Erasures of original field data are not allowed. This includes items such as gage readings, distances, depths, meter revolutions, times, horizontal-angle coefficients, and other field measurements that cannot be repeated. If a variable is remeasured, and it is necessary to change the originally recorded value of that variable, cross it out and record the new measurement above or adjacent to the original. The original measurement should remain legible, even though it is crossed out. On the other hand, it is permissible to erase computed values, such as velocities, areas, widths, and discharges.

Standard Paper Note Keeping for an ADV Discharge Measurement

Paper note sheets, as shown in figure 2B, are the traditional method to record the field observations for an ADV discharge measurement. If using paper note keeping with an ADV for each measurement, the hydrographer should record the information, at a minimum, as if it were a mechanical velocity-meter discharge measurement, with a few variations. Indicate the filename of the infield diagnostic test performed on the ADV during the discharge measurement. Fill in all items on the front sheet or mark with a dash after the measurement is completed and computed.

ADV Inside Notes

An electronic summation of an ADV discharge measurement is produced by the ADV software. This information contains much of the information on the front sheet of the standard discharge measurement form, plus depths, widths, velocities, angles, area, and discharge. Typically ADV software does all the computations for an ADV discharge measurement. Print this output and attach it to the discharge measurement form for archival. Recent programming with personal digital assistants (PDAs) has further facilitated the collection, processing, and entry of discharge measurements into digital databases. See the sections entitled "Electronic counters" and "Other electronic counters, electronic field notebooks, and personal digital assistants" for further discussion of the use of PDAs for field measurements.

Mean Gage Height of Discharge Measurements

The mean gage height of a discharge measurement represents the mean height of the stream during the period the measurement was made and is referenced to the datum of the gaging station. Just as an accurate determination of the discharge is important, so is an accurate determination of the mean gage height because it is one of the coordinates used in plotting the discharge measurement to establish the stage-discharge relation. The computation of the mean gage height presents no problem when the change in stage is small (0.1 ft or less). At gage-height changes of less than 0.1 ft, the mean gage height for the discharge measurement can be obtained by averaging the gage heights at the beginning and end of the measurement, without significant error. Measurements, however, must sometimes be made during floods or regulation when the stage significantly changes more than 0.1 ft.

To compute an accurate mean gage height for a discharge measurement, read the gage at the beginning and end of the discharge measurement, and several times during the measurement if there are significant changes. If the station is equipped with an electronic data logger or DCP that automatically records at intervals of 15 minutes or less, you can take the intermediate gage-height readings from those instruments after the measurement is completed. The hydrographer should accurately synchronize watch time and recorder time, and should record watch time for selected verticals at intervals during the discharge measurement. If the recording interval is greater than 15 minutes (that is, 30 minutes or 1 hour), intermediate gage-height readings should be obtained by reading the gage once or twice during the discharge measurement.

If the change in stage during the measurement is greater than about 0.1 ft (Rantz, 1982, suggests a change of 0.15 ft), the mean gage height should be computed by weighting the gage-height readings. In the past, the mean gage height was computed by weighting the gage readings with partial discharges from the discharge measurement. Later studies show, however, that this method tends to overestimate the mean gage height. Time weighting has also been used to compute a weighted mean gage height, but this method tends to underestimate the mean gage height. Therefore, it is recommended that both methods of weighting be used for discharge measurements having stage changes of 0.10 or more, and that an average of the two results be used for the mean gage height.

Plot the gage-height readings so that intermediate readings can be interpolated where necessary. Pay particular attention to breaks in the slope of the gage-height graph. Figure 25 illustrates a plot of gage heights for a discharge measurement. Gage heights for this measurement were determined from the stage recorder at 15-minute intervals.

In the discharge-weighting procedure, the partial discharges measured between recorded watch times are used with the mean gage height for that same time period. The equation used to compute the weighted mean gage height is:

$$H = \frac{q_1 h_1 + q_2 h_2 + q_3 h_3 + \dots + q_n h_n}{Q} \tag{11}$$

where H weighted mean gage height, in feet,
 Q total discharge measured, in cubic feet per second = $q_1 + q_2 + q_3 + \dots + q_n$,
 $q_1, q_2, q_3, \dots, q_n$ amount of discharge measured during time interval 1, 2, 3... n , in cubic feet per second,
 $h_1, h_2, h_3, \dots, h_n$ average gage height during time interval 1, 2, 3... n , in feet.

Figure 25 shows the computation of a discharge-weighted mean gage height. The graph at the bottom is a reproduction of the gage-height graph during the discharge measurement. To help explain the method, the discharges are taken from the current-meter measurement shown in figure 2A. The upper computation of the mean gage height in figure 25 shows the computation using the given formula. The lower computation was calculated using a shortcut method to eliminate the multiplication of large numbers. In this method, after the average gage height for each time interval has been computed, a base gage height, which is usually equal to the lowest average gage height, is chosen. Then, the difference between the base gage height and the average gage heights is used to weight the discharges. When the mean difference has been computed, the base gage height is added to it.

In the time-weighting procedure, the arithmetic mean gage height for time intervals between breaks in the slope of the gage-height graph is used with the duration of those time periods. The equation used to compute mean gage height is

$$H = \frac{t_1 h_1 + t_2 h_2 + t_3 h_3 + \dots + t_n h_n}{T} \tag{12}$$

where H weighted mean gage height, in feet,
 T total time for the measurement, in minutes ($t_1 + t_2 + t_3 + \dots + t_n$),
 $t_1, t_2, t_3, \dots, t_n$ duration of time intervals between breaks in the slope of the gage height graph, in minutes, and
 $h_1, h_2, h_3, \dots, h_n$ average gage height, in feet, during time interval 1, 2, 3, ..., n .

Using the data from figure 25, the computation of the time-weighted mean gage height is as follows:

Average gage height (h) in ft	Time interval (t) in minutes	$h \times t$
1.92	15	28.80
1.70	15	25.50
1.67	15	25.05
1.88	15	28.20
Totals	60	107.55

The mean gage height is computed as $H = 107.55/60 = 1.79$ ft.

In this example, there is little difference between the discharge-weighted mean gage height (1.77 ft) and the time-weighted mean gage height (1.79 ft). The average of the

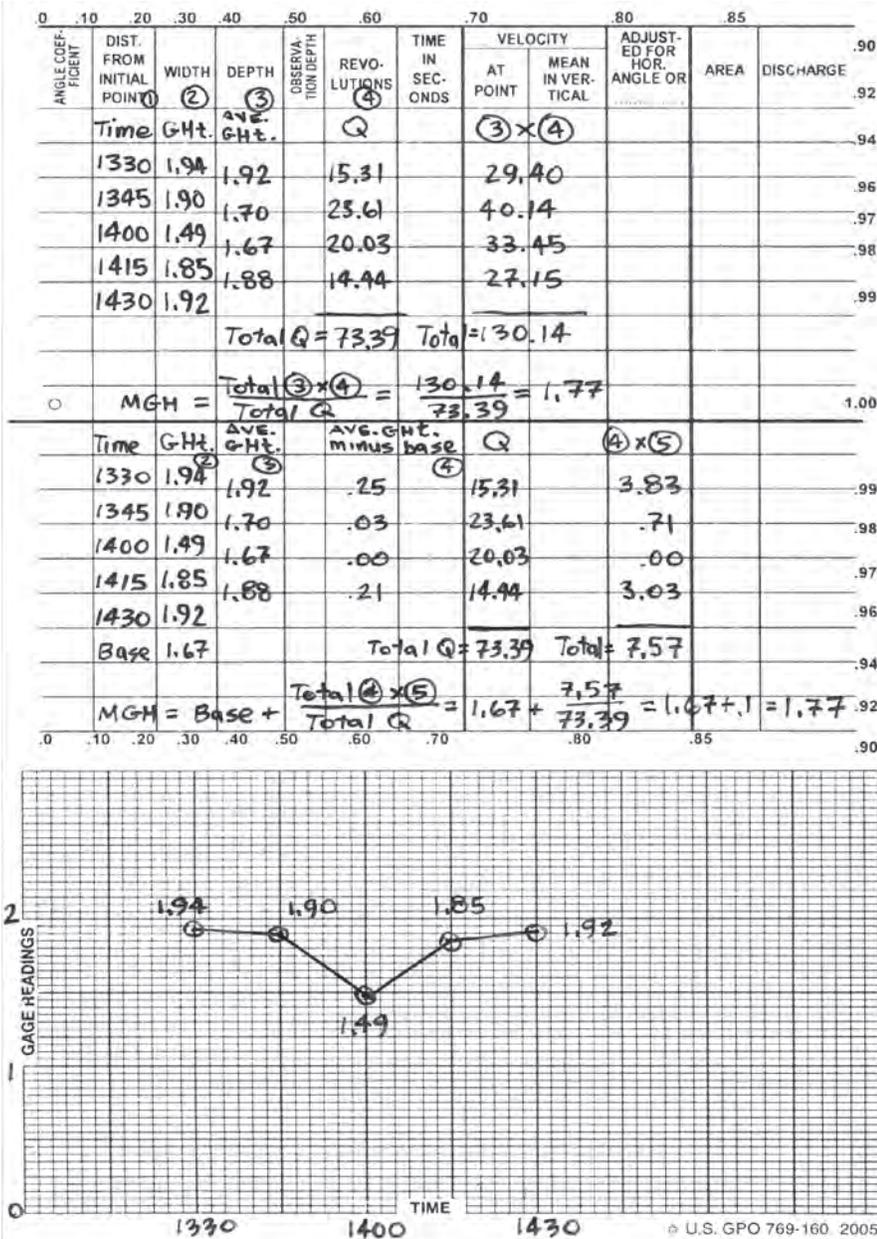


Figure 25. Graph of readings used to compute a weighted mean gage height.

two values, 1.78 ft, is the preferred mean gage height for the discharge measurement.

When extremely rapid changes in stage occur during a measurement, the weighted mean gage height is not truly applicable to the discharge measured. To reduce the range in stage during the measurement, try to reduce the time required for making the discharge measurement; however, keep in mind

that shortcuts in the measurement procedure usually reduce the accuracy of the measured discharge. Therefore, measurement procedures during rapidly changing stage must be optimized to produce a minimal combined error in measured discharge and computed mean gage height. The following section of this chapter describes procedures for making discharge measurements during periods of rapidly changing stage.

Discharge Measurements During Rapidly Changing Stage

Discharge measurements during periods of rapidly changing stage are more difficult to obtain, and accuracy is often not as good as for measurements made when the stage is fairly constant. The computation of total discharge and the corresponding stage are both subject to more uncertainty when the stage significantly changes during the period of the measurement. Two procedures are suggested for shortening the time required for a discharge measurement. The first procedure is applicable more for large streams where the stage changes are usually not as great as for small streams. The second procedure is designed more for the flash-flood conditions experienced with small streams, where peaks can be of momentary duration, and where the rising and falling stage is rapid. Keep in mind that the moving-boat ADCP discharge measurement can be used during these conditions. For a more detailed discussion of procedures for using an ADCP moving-boat during rapidly changing stage, see Mueller and Wagoner (2009).

Measurements of Large Streams With Rapidly Changing Stage

During periods of rapidly changing stage in a large stream, make measurements as quickly as possible to keep the change in stage to a minimum. This will minimize discharge errors caused by the shifting of flow patterns and other variables as the stage changes, and will provide a more accurate stage computation for the measurement. To reduce the time required for making a discharge measurement, make fewer than the usual number of observations and shorten the time to make them. This is sometimes referred to as a shortcut method. Following is a list of some of the things that can be done to reduce the time:

1. Use the 0.6-depth method rather than the 0.2 and 0.8 method. If the 0.6 method cannot be used because the flow is too swift, or if debris makes it too hazardous, then use the 0.2-depth method or the subsurface method. If an optical meter is available, use surface-velocity measurements.
2. Reduce the velocity observation time to about 20 to 30 seconds. This is referred to as half-counts.

3. Only measure about 15 to 18 sections. For some conditions, even use less than 15 sections may be used.
4. Observe and record the watch time at about every third vertical. If possible, observe and record the stage once or twice during the measurement.

By incorporating the above practices, a measurement can usually be made in 15 to 20 minutes. The surface or subsurface method for observing velocities is used, then some vertical-velocity curves will be needed later to establish coefficients to convert observed velocity to mean velocity. Compute a weighted mean gage height for the discharge measurement, as described in a previous section of this chapter.

Use the determination of error in discharge measurements, as described by Sauer and Meyer (1992), to illustrate the difference in errors between the standard measurement procedure and the shortcut procedure. The results shown in table 9 are based on a firm and smooth streambed. The additional uncertainty caused by using the shortcut method is generally less than the error that can be expected from the shifting of flow patterns and other variables that may occur during periods of rapidly changing stage.

Measurements of Small Streams With Rapidly Changing Stage

A series of “instantaneous” discharge measurements can be made during flash flood conditions on small streams by rating individual subsections, or verticals. This method requires repeated observations of gage height, depth, and velocity at selected verticals during the rise and fall of the flood wave. Two procedures are described below, with the primary difference being the method of determining depth at each vertical. In the first procedure, the streambed elevation referenced to gage datum is predetermined for each selected vertical. Depth is then determined as the difference between the gage height and the streambed elevation. In the second procedure, depth is measured at the selected verticals by sounding each time velocity is observed. The first procedure is faster; however, it may not be suitable if the streambed is unstable.

The method of computing the discharge measurements is also slightly different for the two procedures. For both procedures, a rating of gage height versus mean velocity is required

Table 9. Comparison of discharge measurement error for standard and shortcut methods.

[No., number; s, seconds; ft/s, feet per second; ft, feet]

Measurement	Meter type	No. of verticals	Points in vertical	Suspension	Observation time, s	Mean velocity, ft/s	Mean depth, ft	Uncertainty percent	Measurement rated
Standard	AA	30	2	cable	50	2.50	10.0	2.3	Excellent/good.
Shortcut	AA	15	1	cable	25	2.50	10.0	5.1	Good/fair.

for each subsection, or vertical. For the second procedure, a rating of gage height versus depth is required for each vertical. The two procedures are described below.

Procedure 1—Depth Is Computed From Predetermined Streambed Elevations at Each Vertical

1. Select about 10 verticals, or subsections. For very small streams, you may use fewer verticals. Mark the selected verticals in some way so that repeated observations can be made at the same vertical each time.
2. Determine the streambed elevation referenced to gage datum for each selected vertical prior to making the series of discharge measurements. After the flood recedes, determine the streambed elevations at each vertical again to see if changes occurred during the flood. If the streambed is not stable, it will be necessary to interpolate the changes based on time and the best judgment of the hydrographer. Depth is determined at each vertical as the difference between this elevation and the gage height.
3. Take velocity observations at each vertical using the 0.6-depth method. Full counts of 40 seconds or more are recommended, but half-counts may be used if the stream is rising or falling extremely fast. If the 0.6 method cannot be used, then take velocity observations at the 0.2 depth or the subsurface depth. If an optical or other approved noncontact flowmeter is available, use it to take surface-velocity readings. For surface- and subsurface-velocity readings, it will be necessary to determine the coefficient required for converting the readings to a mean velocity. Meter positions should be based on the depth, as computed in item 2 above.
4. Make observations of other factors that would affect the computation of discharge, such as horizontal-angle coefficients.
5. Repeat the velocity and other observations at each of the selected verticals several times over the duration of the flood wave.
6. Record the watch time of each vertical measurement, and make corresponding gage-height observations frequently during the period of the flood wave.
7. Develop a rating of gage height versus mean velocity for each of the selected verticals. If surface- or subsurface-velocity observations were made, apply adjustments so that the rating represents mean velocity in the vertical. In some cases, it may be necessary to develop more than one rating for each vertical. For instance, a rating for the rising side of the flood wave, and a separate rating for the falling side of the flood wave, may be necessary.
8. Select a gage height for which a discharge measurement is to be computed. Use a standard discharge measurement note sheet for computing the discharge measurement.

Enter the stationing for the edge of water and for each of the selected verticals. Enter the depths at each vertical, computed on the basis of the selected gage height minus the streambed elevation. Enter the mean velocity at each vertical on the basis of the gage height versus mean velocity ratings. Enter other adjustments, such as horizontal-angle coefficients, as observed during the observation of velocities. Compute the discharge measurement similar to a regular discharge measurement.

9. Repeat the process described in item 8 above for other selected gage heights. If the ratings of gage height versus mean velocity change, such as for rising and falling stage, then compute separate discharge measurements for the rising and falling limbs of the flood wave.

Procedure 2—Depth Is Measured by Sounding at Each Vertical

1. Select about 10 verticals, or subsections, as described in the first procedure above. For very small streams, fewer verticals may be used. Mark the selected verticals in some way so that repeated observations can be made at the same vertical each time.
2. Determine the depth for each selected vertical by sounding the streambed each time you measure a vertical. Use this method when it is possible to easily make soundings, and when there is a likelihood of streambed elevation changes caused by scour or fill during the course of the measurement.
3. Take velocity observations at each vertical using the 0.6-depth method. Full counts of 40 seconds or more are recommended, but half-counts may be used if the stream is rising or falling extremely fast. It is not likely that you will need to make surface or subsurface observations because depth soundings are possible with this procedure. Meter positions should be based on the sounded depth.
4. Make observations of other factors that would affect the computation of discharge, such as horizontal-angle coefficients.
5. Repeat the observations of depth, velocity, and other variables at each of the selected verticals several times over the duration of the flood wave.
6. Record the watch time of each vertical measurement, and make frequent, corresponding gage-height observations during the period of the flood wave.
7. Develop a rating of gage height versus mean velocity for each of the selected verticals. As described in the first procedure, it may be necessary to develop more than one rating, such as for the rising and falling sides of the flood wave.
8. Develop a rating of gage height versus depth for each of the selected verticals. If streambed changes occur during the measurements, it will be necessary to take these into account by making appropriate corrections.

9. Select a gage height for which a discharge measurement is to be computed. Using a standard discharge-measurement note sheet, enter the stationing for the edge of water and for each of the selected verticals. Enter the depths at each vertical, based on the selected gage height and the ratings of gage height versus depth. Enter the mean velocity at each vertical on the basis of the gage height versus mean velocity ratings. Enter other adjustments, such as horizontal-angle coefficients, as observed during the observation of depths and velocities. Compute the discharge measurement similar to a regular discharge measurement.
10. Repeat the process described in item 9 above for other selected gage heights. If the depth and (or) mean velocity ratings change, such as for rising and falling stage, or for streambed scour or fill, then compute separate discharge measurements for conditions before and after the changes.

Correction of Discharge for Storage During Measurement

Most discharge measurements are made at or near the gaging station and the gage control. However, at some gages, it may be necessary to make discharge measurements at a substantial distance away from the gage and (or) control. For instance, during a flood, the only place to measure may be at a bridge located some distance from the gage. Or for some sites, the low-water section control may be located at a substantial distance downstream from the gage. If a discharge measurement is made at a substantial distance from the gage control during a change in stage, the discharge passing the control during the measurement will not be the same as the discharge at the measurement section. In these situations, an adjustment must be applied to the measured discharge to account for the change in channel storage that occurs between the measurement section and the control during the period of the measurement. The adjustment for channel storage is computed by multiplying the channel surface area by the average rate of change in stage in the reach between the measurement section and the control. The equation is

$$Q_G = Q_m \pm WL \frac{\Delta h}{\Delta t}, \quad (13)$$

- where Q_G discharge going over the control, in cubic feet per second,
 Q_m measured discharge, in cubic feet per second,
 W average width of stream between measuring section and control, in feet,
 L length of reach between measuring section and control, in feet,
 Δh average change in stage in the reach L during the measurement, in feet, and
 Δt elapsed time during measurement, in seconds.

Determine the change in stage at each end of the reach (that is, at the control and at the measuring section) and use an average of these two values. Generally, the gage height at the gage is used at one end of the reach, and a reference point (RP) or a temporary gage is set at the other end of the reach. The water-surface elevation at each end of the reach is determined before and after the measurement to compute Δh . If the measurement is made upstream from the control, the adjustment will be plus for falling stages and minus for rising stages; if it is made downstream from the control, it will be minus for falling stages and plus for rising stages.

An example computation for a flood measurement that was made 0.6 mile upstream from the gage (and control) during a period of changing stage is shown below:

- Measurement made 0.6 mile upstream, $L = 3,170$ feet. Average width between measuring section and control, $W = 150$ ft.
- Gage height at beginning of measurement, at the gage (and control) = 5.84 ft. Gage height at end of measurement, at the gage (and control) = 6.74 ft. Change in stage at gage (and control), $6.74 - 5.84 = +0.90$ ft.
- Gage height at beginning of measurement, at measuring section, = 12.72 ft. Gage height at end of measurement, at measuring section = 13.74 ft. Change in stage at measuring section, $13.74 - 12.72 = +1.02$ ft.

Readings taken at measuring section from a reference point before and after measurement.

- Average change in stage in the reach, $Dh = (0.90 + 1.02)/2 = 0.96$ ft. Elapsed time during measurement, $Dt = 1.25$ hours = 4,500 seconds. Measured discharge, $Q_m = 8,494$ ft³/s.

$$Q_G = 8,494 - \left(150 \times 3,170 \times \frac{0.96}{4,500} \right) = 8,494 - 101 = 8,393 \frac{ft^3}{s}, \quad (14)$$

This discharge should then be rounded to 8,390 ft³/s, which represents the discharge at the gage, or control.

The adjustment of the measured discharge for storage between the gage (or control) and measuring site, as described above, is a separate and distinct problem from that of making adjustments owing to variable water-surface slopes caused by changing discharge. Those adjustments are related to stage-discharge rating analysis, and are described by Kennedy (1984), and by Rantz (1982). The storage adjustment they described should be made immediately following the completion of the discharge measurement, and the resulting adjusted discharge is later used for rating analysis.

Instruments and Equipment

Point-velocity current-meter and profiler measurements are usually classified in terms of the method used to cross the stream during the measurement (that is, wading, bridge, cableway, or ice), the method used to compute the discharge, such as midsection, ADCP, flume, or volumetric, and the method used to compute the velocity (if applicable to the discharge method), such as Price AA meter, ADCP, or ADV. Instruments and equipment used in making current-meter measurements will vary, depending upon which of these measurement types are being used. Current meters, timers, and electronic and other counting equipment are generally common to all types of current-meter and profiler measurements. This section describes equipment currently used by USGS field offices.

Current Meters

A point-velocity current meter, in the context of this report, is a precision instrument calibrated to measure the velocity of flowing water in a single point or fixed volume. Several types of current meters are available for use, including rotating-element mechanical meters, electromagnetic meters, acoustic Doppler velocimeters (ADV or FlowTrackers), acoustic digital current meters (ADCs), and optical meters.

The principle of operation for a mechanical meter is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a mechanical current meter at a point in a stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point can be determined from the meter rating.

An electromagnetic current meter is based on the principle that a conductor (water) moving through a magnetic field will produce an electrical current. By measuring this current and the resultant distortion in the magnetic field, the instrument can be calibrated to determine point velocities of flowing water.

The acoustic meter or profiler (for example, ADV or ADCP) uses the Doppler principle to determine velocities of flowing water. Acoustic meters and profilers have been developed to measure point velocities in the vertical profile of an open-channel flow, as well as multicell vertical-velocity profiles. The ADCP has been adapted for use with the moving-boat method of measuring discharge, as described by Mueller and Wagner (2009). The ADV has been developed and adapted to mount on the standard USGS wading rod to measure point velocities in a manner similar to the method for measuring velocity with a vertical-axis rotating-element mechanical meter. ADVs will be described in a later section of this chapter.

The following sections describe the various types of current meters and profilers in more detail, give advantages and disadvantages of each, and provide guidance on care and maintenance.

Current Meters—Mechanical and Vertical Axis

Historically, the most commonly used meter by the USGS to measure open-channel velocities in rivers and streams has been the vertical-axis, mechanical current meter. The original prototype for this kind of current meter was designed and built in 1882 by W.G. Price, while he was working with the Mississippi River Commission. The Price current meter has evolved through a number of different models and refinements since 1882, but the basic theory and concepts remain the same. The Price AA meter is the most commonly used mechanical current meter for discharge measurements made by the USGS; however there are other variations of this meter, such as the Price AA slow velocity, the Price pygmy, and the Price AA winter meter. The following sections describe the various Price meters in more detail, and table 10 summarizes the various configurations and recommendations for the Price current meter, Price AA low velocity, the Price pygmy, the Price AA winter yoke with polymer and metal cups, and the SonTek FlowTracker ADV.

Price AA Meter

Historically, most current-meter measurements made by the USGS have been made with the vertical-axis Price AA and the Price pygmy current meters, as shown in figures 26 and 27. The basic components of the Price AA meter include the shaft and rotor (bucket wheel) assembly, the contact chamber, the yoke, and the tailpiece. The rotor, or bucket wheel, is 5 in. in diameter and 2 in. high with six cone-shaped cups mounted on a stainless-steel shaft. A vertical pivot supports the vertical shaft of the rotor, hence the name vertical-axis current meter. The contact chamber houses the upper part of the shaft and provides a method of counting the number of revolutions the rotor makes. A reduction gear (commonly referred to as the penta gear) on the lower part of the shaft allows counting every fifth revolution of the rotor when it is activated. The penta gear is used in discharge measurements with very high velocities. Contact chambers that can be used on the Price AA meter are described in a later section of this chapter. The yoke is the framework that holds the other components of the meter. A tailpiece is used for balance and keeps the meter pointing into the current.

When placed in flowing water, the rotors of the Price current meters turn at a speed proportional to the speed of the water. For practical purposes, these current meters are considered nondirectional because they register the maximum velocity of the water, even though they may be placed at an angle to the direction of flow. Advantages of the vertical-axis current meter are:

1. They operate in lower velocities than do horizontal-axis meters.
2. Bearings are well protected from silt-laden water.
3. The rotor is easily repairable in the field without adversely affecting the rating.
4. USGS standard ratings apply to the Price AA and Price pygmy meters.
5. A single rotor serves for the entire range of velocities.

Table 10. Price current meter and SonTek ADV configurations, usages, and recommended ranges of depth (without boundary interference) and velocity.

Meter	Contact chamber	Counting method	Rating	Velocity range, feet per second ¹	Depth range, feet	Remarks
Price AA	Standard, cat's whisker and penta gear	Headphones, CMD ² , or EFN ³	Standard	0.2 to 12	1.25 or greater	The Price AA meter can be used as a low-velocity meter if equipped with an optic contact chamber.
			Individual	0.1 to 12		
	Magnetic	CMD ² or EFN ³	Standard	0.2 to 12		
			Individual	0.1 to 12		
Optic		Standard or individual	0.1 to 12			
Price AA, low velocity	Cat's whisker with double contact lobe on shaft. No penta gear.	Headphones, CMD ² , or EFN ³	Individual	0.1 to 12	1.25 or greater	This is the traditional Price AA low velocity meter. An individual rating is recommended; however, a standard rating can be used if less accuracy is acceptable.
Price pygmy	Cat's whisker	Headphones, CMD ² , or EFN ³	Standard or individual	0.2 to 4.0	0.3 to 1.5	--
Price, winter WSC ⁴ yoke, polymer cups	Cat's whisker	Headphones, CMD ² , or EFN ³	Individual, with suspension device	0.1 to 12	1.25 or greater	This meter is recommended for conditions where slush ice is present.
	Magnetic or Optic	CMD ² or EFN ³				
Price, winter WSC ⁴ yoke, metal cups	Cat's whisker	Headphones, CMD ² , or EFN ³	Individual, with suspension device	0.1 to 12	1.25 or greater	This meter is recommended for conditions where slush ice is not present.
	Magnetic or Optic	CMD ² or EFN ³				
SonTek FlowTracker ADV	N/A	N/A	Individual	0.003 to 13 ⁵	0.25 or greater	The FlowTracker has been documented by the USGS to provide velocities comparable to mechanical vertical axis current meters.

¹Low- and high-velocity limits shown in the table are based on a small-to-moderate extrapolation of the lower and upper meter calibration limits. It is not recommended that the meters be used for velocities less than the lower limit. The velocity rating for the Price meter may allow additional extrapolation in the upper range to about 20 feet per second. The upper range of the Price pygmy meter rating may be extrapolated to about 5 feet per second. Standard errors within the meter calibration limits are less than $\pm 5\%$ in all cases. Standard errors in the extrapolated range of velocities are unknown, but are probably within $\pm 5\%$.

²Current-meter digitizer. Observe cautions for low velocities. See text.

³Electronic field notebook, such as Aquacalc or DMX. Observe cautions for low velocities. See text.

⁴Water Survey of Canada.

⁵Manufacturer's specification.

Price AA Meter (Slow Velocity)

In addition to the Price AA meter described above, there is a Price AA meter modified slightly for use in measuring low velocities. To reduce friction, the penta gear has been removed from this meter, and the shaft has two eccentrics making two contacts with the cat's whisker per revolution. The low-velocity meter normally is rated from 0.2 to 2.5 ft/s and is recommended when the mean velocity at a cross section is less than 1 ft/s.

Price Pygmy Meter

A miniature version of the Price AA meter is the Price pygmy meter, as shown in figures 26 and 27, which is used for measuring velocities in shallow depths. The Price pygmy meter is scaled two-fifths the size of the standard meter and has neither a tailpiece nor a penta gear. The contact chamber is an integral part of the yoke of the meter. The Price pygmy meter makes one contact for each revolution and is used only for rod suspension.

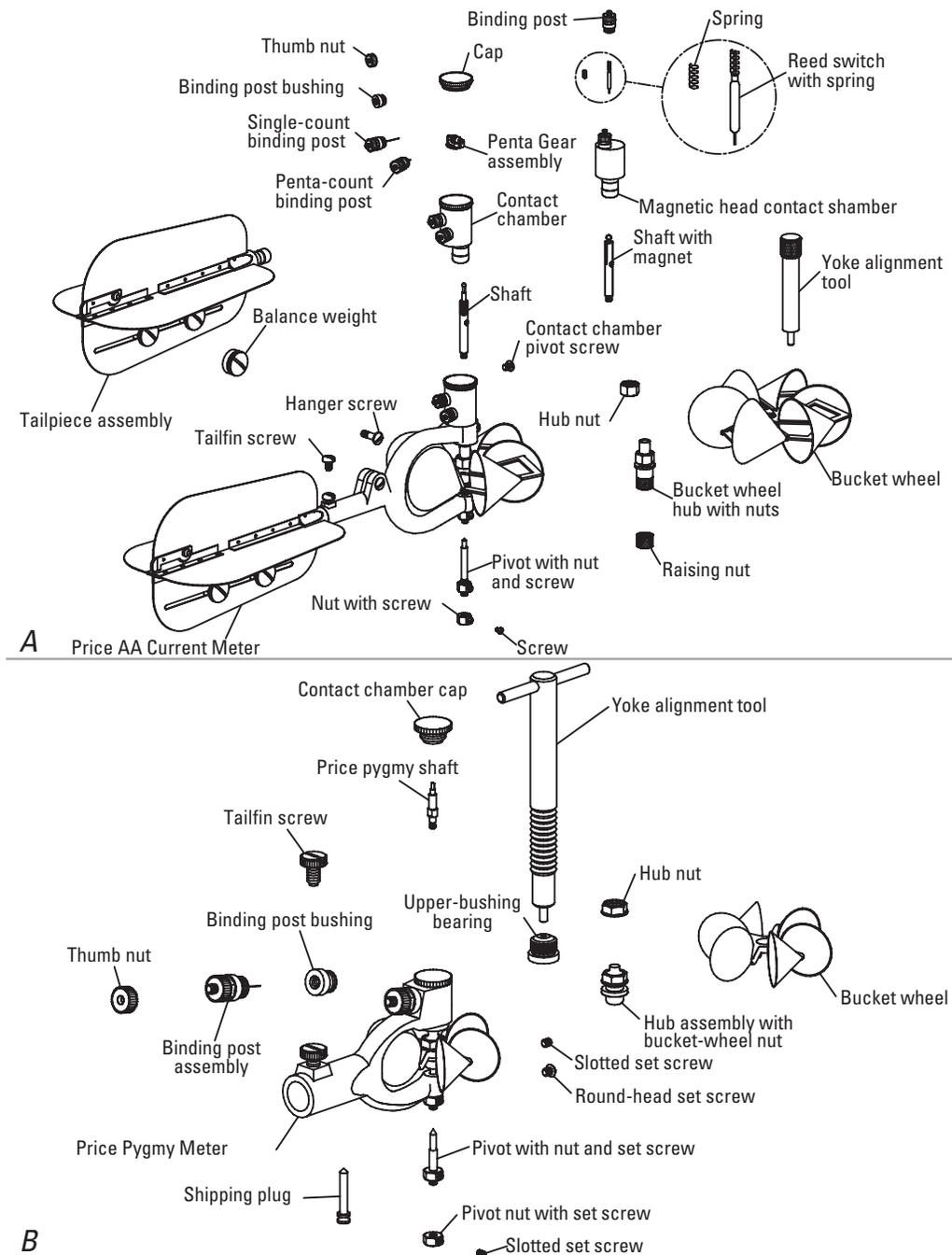


Figure 26. Assembly drawing of the A, Price AA current meter and B, Price pygmy current meter.



Figure 27. A, Price AA and B, Price pygmy current meters.

Price AA Winter Meter

In streams where slush ice is present, use a modified Price AA meter, as shown in figure 28. This meter is built with a WScan winter-style yoke, and uses a polymer rotor (bucket wheel) in place of the standard metal-cup rotor. The WScan winter-style yoke meters require an individual rating due to increased tolerances in manufacturing. The solid polymer rotor has the advantage that it does not fill with slush ice during a measurement, and the slush ice does not easily adhere to it. If slush ice is not present, alternative methods can be used, including replacing the polymer rotors with metal cups or using a pygmy meter. Regular Price AA meters with metal-cup rotors are also acceptable for slush-free conditions, if there are no problems with cutting the required larger holes through the ice. In recent years, the USGS has increasingly used ADCPs and ADVs as alternatives to the Price AA for making discharge measurements in streams where ice is present.



Figure 28. Price AA meter with winter-style yoke and polymer rotor.

Current Meters—Mechanical and Horizontal Axis

A number of mechanical current meters are available that have a propeller-, or vane-, type of rotor mounted on a horizontal shaft. These meters are used extensively in Europe and some Asian countries, but very little in the United States, and are generally not recommended by the USGS because they are not as durable as the Price current meter. Horizontal-axis current meters include the Ott (Germany), Neyrpic (France), Haskell (U.S.), Hoff (U.S.), Braystoke (United Kingdom), and Valeport. Various models of each of these are also available. As a group, horizontal-axis current meters have the following advantages:

1. The rotor, or propeller, disturbs flow less than vertical-axis rotors because of axial symmetry with flow direction.
2. The rotor is less likely to be entangled by debris than vertical-axis rotors.
3. Bearing friction is less than for vertical-axis rotors because bending moments on the rotor are eliminated.
4. In oblique currents, some of these meters (for example, the Ott meter) measure the velocity normal to the measuring section when the meter is held normal to the measuring section.
5. Rotors with propellers of different pitches are available for some of the meters, allowing measurement of a considerable range of velocity.

See figures 29, 30, and 31, respectively, for examples of the Ott, Hoff, and Valeport current meters.

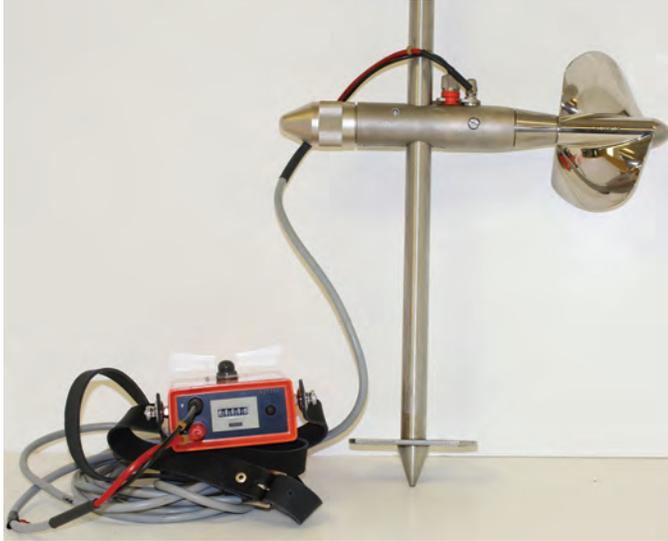


Figure 29. Ott current meter.

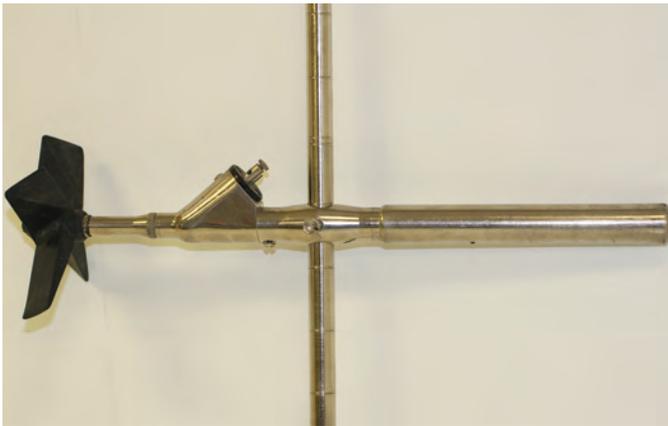


Figure 30. Hoff current meter.



Figure 31. Valeport current meter.

Current-Meter Contact Heads (Vertical Axis)

The Price current meter is normally fitted with a contact chamber that has a cat's-whisker type of circuitry used for counting the number of revolutions of the rotor. Two other types of contact chambers—the magnetic switch type and the optical type—can be fitted to the Price AA meter.

Cat's Whisker

When placed in flowing water, the rotor of the current meter turns at a speed proportional to the speed of the water. The number of revolutions of the rotor is obtained by counting electrical impulses generated in the contact chamber. An eccentric contact on the upper end of the rotor shaft wipes a slender alloy wire (cat's whisker) attached to the binding post, which closes an electrical circuit. This electrical impulse produces an audible click in a headphone or registers a unit on a counting device. Contact points in the chamber are designed to complete the electrical circuit at selected frequencies of revolution, such as twice per revolution, once per revolution, or once per five revolutions (by use of the penta gear). The penta gear, wire, and binding post provide a contact each time the rotor makes five revolutions. Figure 32 shows the contact chamber and shaft for the cat's-whisker-type chamber, with a single-count binding post.

Two types of cat's-whisker wires have been used: one is the simple bronze wire, and the other is the old type of wire with a small solder bead on the end of it. Adjust the cat's whisker for the penta gear so that it always touches the penta eccentric, even when the penta counter is not in use. Otherwise, the meter rating may be affected.

Magnetic Switch

A contact chamber housing a magnetic-type switch, as shown in figure 32, is available to replace the cat's-whisker-contact chamber. The magnetic switch is composed of glass that is enclosed in a hydrogen atmosphere and hermetically sealed. The switch assembly is rigidly fixed in the top of the meter head just above the tip of the shaft. The switch is operated by a small permanent magnet rigidly fastened to the shaft. Two types of magnets used: (1) a bar magnet and (2) a circular magnet. If the contact chamber uses the bar magnet, it should be identified with an "A" stamped on the top surface of the chamber to indicate it has been modified. Older, unmodified contact chambers with the bar magnet were found to under-register for velocities greater than about 2 ft/s. The chambers that utilize the circular magnets fit the standard rating throughout its range.

The magnetic switch quickly closes when the magnet is aligned with it, and then promptly opens when the magnet moves away. The magnet is properly balanced on the shaft. Any type of AA meter can have a magnetic switch added by replacing the shaft and the contact chamber. The magnetic switch is placed in the contact chamber through the tapped hole for the binding post. The rating of the meter is not altered by the change.

An automatic counter, as described in a later section of this chapter, is used with the magnetic-switch contact chamber. Do not use a headphone with the magnetic head because arcing can weld the contacts.



Figure 32. A, Price AA magnetic head current meter contact chamber; B, single count binding post; and C, shaft with magnet for magnetic heads.

Optical Head

A contact head utilizing fiber-optics technology is available for reading the pulse rate of the Price AA current meter. A special rotor containing two fiber-optic bundles is attached to the upper end of the bucket-wheel shaft. The rotation of these fiber-optic bundles gates infrared light from a photo diode to a photo transistor, creating a pulse rate that is proportional to the rotor's revolutions. The pulses are counted, stored, and then compared with a quartz crystal oscillator. This information is processed to display stream velocity on a liquid crystal readout. The display has three averaging periods selected by a rotary switch. The averaging periods range from a minimum of about 5 seconds to a maximum of about 90 seconds. The unit is powered by a 9-volt battery.

Output of pulses from the optical sensing unit can be counted by the current-meter digitizer and the electronic field notebooks described in subsequent sections of this chapter. A standard rating table based on tow-tank calibration tests at the USGS Hydrologic Instrumentation Facility (HIF) is used to convert pulse rate to stream velocity.

A special tail-fin assembly is required for the optical meter so it will balance properly when submerged. The vertical section of this tail fin is marked with the letters OAA, and the horizontal section is marked PAA.

Vertical-Axis Current-Meter Timers and Counters

The determination of velocity using a mechanical current meter requires that the number of revolutions of the rotor be counted during a specified time interval, usually 40 to 70 seconds. Several methods are available for timing and counting the revolutions, as described in the following paragraphs.

Stopwatch and Headset

For current meters having a cat's-whisker-type contact chamber, an electrical circuit is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and headphone, as shown in figure 33, are parts of the electrical circuit, and an audible click can be heard in the headphone at each electrical closure. Some hydrographers have adapted compact, comfortable hearing-aid-type phones to replace headphones. Beepers that can be heard without the headset are also sometimes used. Do not use a headset, or similar device, with the magnetic contact chamber because arcing can weld the contacts.

Measure the time interval to the nearest second with a stopwatch. Figure 33 shows the standard analog stopwatch; however, a digital wrist watch can also be used.



Figure 33. A, Analog stopwatch and B, current-meter headset.

Electronic Counters

Current-Meter Digitizer (CMD)

A current-meter digitizer (CMD), or automatic electronic counter, as shown in figure 34, was developed for use with the cat's-whisker-, optic-, and magnetic-contact chambers. It can be used with any of the mechanical, vertical-axis current meters, but be careful to avoid false counts when using it for low velocities when the cat's-whisker-contact chamber is used. The CMD automatically counts and displays the number of revolutions of the current-meter rotor and the elapsed time. A buzzer produces an audible signal at each contact closure, and the total counts and elapsed time are shown in the display at the completion of the velocity measurement. A coded chip can be installed in the CMD that will compute and display the velocity from the standard rating table for the particular meter being used. The CMD is powered with five rechargeable batteries, and has an adapter that can be used to attach it to the top of a wading rod.



Figure 34. Current-meter digitizer.

Other Electronic Counters, Electronic Field Notebooks, and Personal Digital Assistants

Electronic counters and timers for mechanical current meters are also available in some commercially available devices. Electronic field notebooks (EFNs), such as the JBS Instruments Aquacalc Pro Discharge Measurement Computer, are designed for electronic recording of discharge-measurement data. These will be described in more detail in a later section of this chapter. Both the Aquacalc and the Hydrological Services Current Meter Counter signal processor (CMCsp) contain built-in digitizers that count and time the current-meter rotor revolutions. Built-in ratings convert the revolutions and elapsed time to velocity. Just as with the CMD described above, the EFNs should be used with caution to avoid false counts when measuring low velocities with meters equipped with a cat's-whisker-contact chamber.

The USGS is increasing development and use of personal digital assistants (PDAs) for primary data collection and processing of discharge measurements and surface-water field data. Software programs such as the Surface Water Measurement and Inspection application (SWAMI) continue to streamline field activities by reducing the need for paper forms in the field through the development of electronic field forms written for the PDA. SWAMI, as described in previous sections of this chapter, is used in many USGS Water Science Centers, and other PDA applications and programs are continually being developed.

Care of the Vertical-Axis Mechanical Current Meter

There are a number of documents describing the care and maintenance of the vertical-axis current meters. Among these, the most important originated from the USGS and are by Smoot and Novak (1968) and by Rantz (1982), and Office of Surface Water Technical Memorandum No. 89.07 (1989) and Office of Surface Water Technical Memorandum No. 99.06 (1999). These instructions represent a long history of experience based on field use of the meters, as well as from individuals in the Office of Surface Water Hydraulic Laboratory who have repaired and adjusted current meters to calibrate them within close tolerances. A brief description of the recommended procedure for checking the condition of a current meter, and for its care and cleaning during daily field use, is presented in the next few paragraphs. For complete details, consult the above-mentioned documents.

Recommended Procedure Before, During, and After Each Discharge Measurement

1. Before each discharge measurement, make a visual examination of the meter cups or vanes, pivot, bearing, and shaft for damage, wear, or faulty alignment. Inspect the bearing surface for water. This will usually appear as a milky emulsification of oil and water on the lower bearing and pivot, and in the contact chamber. If water is found, dry the meter parts and re-oil because the presence of water will affect the performance of the meter. The lower bearing is probably the most susceptible to the entrance of water.
2. Spin the rotor to make certain it operates freely, and allow it to slowly return to a resting position. If the rotor does not turn smoothly, or if it stops abruptly, then it is a sign of some problem and it should be corrected before using the meter. Check the balance and alignment of the meter on the hanger or wading rod. Be sure that the conductor wire does not interfere with meter balance and rotor spin.
3. During measurements, check the meter periodically when it is out of the water to be sure that the rotor spins freely, and that there is no debris or other substance obstructing it.
4. After a measurement is completed, make another visual inspection as described above to ensure that nothing was damaged or caused the meter to malfunction during the measurement. If there is a problem, you may have to make another discharge measurement.
5. Timed spin tests (described later in this chapter) are not required for each discharge measurement. The visual inspection described above is preferred over timed spin tests made in the field.

Recommended Procedure After a Day of Use in the Field

1. Examine the pivot and bearing surfaces for wear and damage, especially the pivot point. The pivot should feel sharp, not rounded or dull. It should not have a burr detectable visually or with the fingernail. A magnifying glass is helpful in making this examination. If the pivot is dull or burred, replace it with a new one.
2. Clean and lightly oil the pivot, bearing, and upper shaft with current-meter oil. Do not use regular machine oil, such as “3-in-1,” because it tends to become gummy when exposed to water.
3. Check and carefully adjust cat’s-whisker contacts, if necessary. Cat’s whiskers should be made of simple bronze wire, not beaded wire.
4. After replacing the contact-chamber cap, spin the meter to see if it is operating correctly, as previously described. A timed spin test is not required.

Recommended Procedure After Each Field Trip

After each field trip, completely disassemble, inspect, and clean current meters. Make any necessary repairs. Detailed instructions for the disassembly, inspection, and adjustment of Price AA (both standard and magnetic head) and pygmy current meters are contained in the attachments to Office of Surface Water Technical Memorandum No. 99.06 (1999). A timed spin test may also be performed after each field trip, and after meter repairs.

Inactive Current Meters

Disassemble, inspect, and clean current meters as described above, prior to storing them. If the period of storage is less than 1 year, the meter may be used without further maintenance if an inspection and a spin test indicate it is operating properly. If the meter has been in storage longer than 1 year, or an indeterminate period, complete inspection, cleaning, and adjustment before using the meter.

Spin Tests

A timed spin test, made in the field before and after each discharge measurement, is no longer a requirement as it was in the past. The visual tests as described above are adequate for checking the meter in the field. Note “OK” or “free” in the spaces on the front sheet of the discharge measurement for spin test information to indicate that the visual check of the meter was acceptable.

Perform the full-timed spin test under controlled conditions between field trips, when the meter is suspect, and before and after repairs. Place the meter on a stable, level surface to perform the spin test. There should be no wind currents or drafts that can affect the rotor spin. Sharply spin the rotor while starting a stopwatch. Stop the stopwatch when the rotor comes to a complete stop. The minimum, acceptable spin times are as follows:

All types of Price pygmy meters	0:45 seconds
All types of Price AA meters	2:00 minutes

These are considered to be absolute minimum spin times. Meters in good condition will perform substantially better.

Recordkeeping

Maintain a current-meter log to record the results of the timed spin tests for each current meter. In addition, the log should contain information that identifies the meter and rotor, a history of repairs to the meter, as well as the name of the person who checked the meter, and dates of occurrences. Figure 35 shows a recommended format for the current meter log. The current-meter log should become a permanent record and archived with other water-resources data.

Rating of Mechanical Current Meters

In order to determine the velocity of the water from the revolutions of the rotor of a mechanical current meter, a relation must be established between the angular velocity of the rotor and the velocity of the water turning it. This relation is referred to as the current-meter rating, and is expressed in an equation or in tabular format.

The current-meter rating facility is operated by the USGS, and is located at the Hydraulics Laboratory of the HIF at Stennis Space Center, Miss. The rating facility consists of a sheltered, reinforced concrete basin 400 ft long, 6 ft wide, and 6 ft deep, commonly called the tow tank. An electrically driven car rides on rails alongside and extending the length of the water-filled basin, and carries the current meter at a constant rate through the still water. Although the rate of travel can be accurately adjusted by means of a hydraulic regulating gear, the average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the rotor are electrically counted. A scale graduated in feet and tenths of a foot is used for this purpose. Eight pairs of runs are usually made for each current meter. A pair of runs consists of two traverses of the basin, one in each direction, at approximately the same speed. Practical considerations usually limit the ratings to velocities ranging from 0.1 ft/s to about 15 ft/s, although the rating car can be operated at lower speeds. Unless a special request is made for a more extensive rating, the lowest velocity used in the rating is about 0.2 ft/s, and the highest is about 8.0 ft/s.

Because there is rigid control in the manufacture of the Price meter, virtually identical meters are produced and, for practical purposes, their rating equations are identical. Therefore, there is no need to calibrate the meters individually, which is a major advantage and time saver. Instead, a standard rating is established by calibrating a group of meters that have been constructed according to USGS specifications. This standard rating is essentially an average rating for the calibration group, and it is then supplied with all meters manufactured according to USGS specifications. Identicalness of meters is ensured by supplying the dies and fixtures for the construction of Price current meters to the manufacturer who makes the successful bid. Another advantage of the standard rating is that field repairs can be made to a meter without requiring that it be recalibrated. On the other hand, there are somewhat larger errors associated with the standard ratings, as opposed to the individual meter ratings. For additional details see Office of Surface Water Technical Memoranda Nos. 91.01 (1991) and 99.05 (1999).

Standard current-meter ratings are not mandatory for use with the Price meters. For some applications, it may be appropriate to use individually rated meters to avoid the additional

uncertainty of the standard ratings. All winter-style meters must be individually rated with the suspension device that will be used with it.

Standard current-meter ratings, as of 1999, have been defined for the Price AA with the cat's-whisker- and magnetic-contact chambers, and the Price pygmy with the cat's-whisker-contact chamber. The standard rating for the Price AA with the fiber-optic-contact chamber was defined in 1991. These ratings are as follows:

- Price AA with cat's-whisker- and magnetic-contact chambers (Standard rating No. 2)

$$V = 2.2048R + 0.0178 \quad (15)$$

- Price pygmy with cat's-whisker-contact chamber (Standard rating No. 2)

$$V = 0.9604R + 0.0312 \quad (16)$$

- Price AA with fiber-optic-contact chamber

$$V = 2.194R + 0.014 \quad (R < 0.856) \quad (17)$$

$$V = 2.162R + 0.041 \quad (R > 0.856) \quad (18)$$

where V velocity, in feet per second (ft/s), and
 R the number of rotor revolutions per second.

For convenience in field use, the data from the current-meter ratings are reproduced in tables, samples of which are shown in figures 36 and 37. In figure 36, the velocities corresponding to a range of 3 to 200 revolutions of the rotor within a period of 40 to 70 seconds are listed in the tables.

In figure 37, the velocities corresponding to a range of 3 to 350 revolutions of the rotor within a period of 40 to 70 seconds are listed in the tables. This range in revolution and time has been found to cover general field requirements. To provide the necessary information for extending a table for the few instances where extensions are required, the equation of the rating table is shown in the heading.

Meters that have been rated by means of rod suspension, and then by means of cable suspension using Columbus-type weights and hangers, have not shown significant differences in their ratings. Therefore, no suspension coefficients are needed if weights and hangers are properly used.

The preceding discussion relates primarily to the Price current meters. Other types of meters, such as the horizontal-axis meters and the electromagnetic meters, can also be calibrated in the tow tank in a similar manner as the Price meters. The HIF designed and constructed a special tow tank for testing and calibrating the acoustic Doppler point-velocity FlowTracker velocimeter. In the near future, there are HIF plans to build and operate a tow tank designed to test and calibrate ADCPs.

54 Discharge Measurements at Gaging Stations

STANDARD RATING TABLE NO. 2 FOR PYGMY CURRENT METER (6/99)
 EQUATION: $V = 0.9604 R + 0.0312$ (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions														
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200
40	0.103	0.151	0.199	0.271	0.391	0.511	0.631	0.752	0.992	1.23	1.47	1.95	2.43	3.63	4.83
41	0.101	0.148	0.195	0.265	0.383	0.500	0.617	0.734	0.968	1.20	1.44	1.91	2.37	3.54	4.72
42	0.100	0.146	0.191	0.260	0.374	0.489	0.603	0.717	0.946	1.17	1.40	1.86	2.32	3.46	4.60
43	0.098	0.143	0.188	0.255	0.366	0.478	0.590	0.701	0.925	1.15	1.37	1.82	2.26	3.38	4.50
44	0.097	0.140	0.184	0.249	0.359	0.468	0.577	0.686	0.904	1.12	1.34	1.78	2.21	3.31	4.40
45	0.095	0.138	0.181	0.245	0.351	0.458	0.565	0.671	0.885	1.10	1.31	1.74	2.17	3.23	4.30
46	0.094	0.136	0.177	0.240	0.344	0.449	0.553	0.658	0.866	1.08	1.28	1.70	2.12	3.16	4.21
47	0.093	0.133	0.174	0.236	0.338	0.440	0.542	0.644	0.849	1.05	1.26	1.67	2.07	3.10	4.12
48	0.091	0.131	0.171	0.231	0.331	0.431	0.531	0.631	0.832	1.03	1.23	1.63	2.03	3.03	4.03
49	0.090	0.129	0.168	0.227	0.325	0.423	0.521	0.619	0.815	1.01	1.21	1.60	1.99	2.97	3.95
50	0.089	0.127	0.166	0.223	0.319	0.415	0.511	0.607	0.800	0.992	1.18	1.57	1.95	2.91	3.87
51	0.088	0.125	0.163	0.220	0.314	0.408	0.502	0.596	0.784	0.973	1.16	1.54	1.91	2.86	3.80
52	0.087	0.124	0.160	0.216	0.308	0.401	0.493	0.585	0.770	0.955	1.14	1.51	1.88	2.80	3.73
53	0.086	0.122	0.158	0.212	0.303	0.394	0.484	0.575	0.756	0.937	1.12	1.48	1.84	2.75	3.66
54	0.085	0.120	0.156	0.209	0.298	0.387	0.476	0.565	0.743	0.920	1.10	1.45	1.81	2.70	3.59
55	0.084	0.119	0.153	0.206	0.293	0.380	0.468	0.555	0.730	0.904	1.08	1.43	1.78	2.65	3.52
56	0.083	0.117	0.151	0.203	0.288	0.374	0.460	0.546	0.717	0.889	1.06	1.40	1.75	2.60	3.46
57	0.082	0.115	0.149	0.200	0.284	0.368	0.452	0.537	0.705	0.874	1.04	1.38	1.72	2.56	3.40
58	0.081	0.114	0.147	0.197	0.280	0.362	0.445	0.528	0.694	0.859	1.02	1.36	1.69	2.51	3.34
59	0.080	0.113	0.145	0.194	0.275	0.357	0.438	0.520	0.682	0.845	1.01	1.33	1.66	2.47	3.29
60	0.079	0.111	0.143	0.191	0.271	0.351	0.431	0.511	0.671	0.832	0.992	1.31	1.63	2.43	3.23
61	0.078	0.110	0.141	0.189	0.267	0.346	0.425	0.504	0.661	0.818	0.976	1.29	1.61	2.39	3.18
62	0.078	0.109	0.140	0.186	0.264	0.341	0.418	0.496	0.651	0.806	0.961	1.27	1.58	2.35	3.13
63	0.077	0.107	0.138	0.184	0.260	0.336	0.412	0.489	0.641	0.793	0.946	1.25	1.56	2.32	3.08
64	0.076	0.106	0.136	0.181	0.256	0.331	0.406	0.481	0.631	0.782	0.932	1.23	1.53	2.28	3.03
65	0.076	0.105	0.135	0.179	0.253	0.327	0.401	0.474	0.622	0.770	0.918	1.21	1.51	2.25	2.99
66	0.075	0.104	0.133	0.177	0.249	0.322	0.395	0.468	0.613	0.759	0.904	1.20	1.49	2.21	2.94
67	0.074	0.103	0.132	0.175	0.246	0.318	0.390	0.461	0.605	0.748	0.891	1.18	1.46	2.18	2.90
68	0.074	0.102	0.130	0.172	0.243	0.314	0.384	0.455	0.596	0.737	0.879	1.16	1.44	2.15	2.86
69	0.073	0.101	0.129	0.170	0.240	0.310	0.379	0.449	0.588	0.727	0.866	1.14	1.42	2.12	2.81
70	0.072	0.100	0.127	0.168	0.237	0.306	0.374	0.443	0.580	0.717	0.854	1.13	1.40	2.09	2.78
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200

Figure 36. Example of a standard current-meter rating table No. 2 for Price pygmy current meters with cat's-whisker contact chamber.

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
 EQUATION: $V = 2.2048 R + 0.0178$ (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND								Seconds	
	Revolutions									
	50	60	80	100	150	200	250	300	350	
40	2.77	3.33	4.43	5.53	8.29	11.04	13.80	16.55	19.31	40
41	2.71	3.24	4.32	5.40	8.08	10.77	13.46	16.15	18.84	41
42	2.64	3.17	4.22	5.27	7.89	10.52	13.14	15.77	18.39	42
43	2.58	3.09	4.12	5.15	7.71	10.27	12.84	15.40	17.96	43
44	2.52	3.02	4.03	5.03	7.53	10.04	12.55	15.05	17.56	44
45	2.47	2.96	3.94	4.92	7.37	9.82	12.27	14.72	17.17	45
46	2.41	2.89	3.85	4.81	7.21	9.60	12.00	14.40	16.79	46
47	2.36	2.83	3.77	4.71	7.05	9.40	11.75	14.09	16.44	47
48	2.31	2.77	3.69	4.61	6.91	9.20	11.50	13.80	16.09	48
49	2.27	2.72	3.62	4.52	6.77	9.02	11.27	13.52	15.77	49
50	2.22	2.66	3.55	4.43	6.63	8.84	11.04	13.25	15.45	50
51	2.18	2.61	3.48	4.34	6.50	8.66	10.83	12.99	15.15	51
52	2.14	2.56	3.41	4.26	6.38	8.50	10.62	12.74	14.86	52
53	2.10	2.51	3.35	4.18	6.26	8.34	10.42	12.50	14.58	53
54	2.06	2.47	3.28	4.10	6.14	8.18	10.23	12.27	14.31	54
55	2.02	2.42	3.22	4.03	6.03	8.04	10.04	12.04	14.05	55
56	1.99	2.38	3.17	3.95	5.92	7.89	9.86	11.83	13.80	56
57	1.95	2.34	3.11	3.89	5.82	7.75	9.69	11.62	13.56	57
58	1.92	2.30	3.06	3.82	5.72	7.62	9.52	11.42	13.32	58
59	1.89	2.26	3.01	3.75	5.62	7.49	9.36	11.23	13.10	59
60	1.86	2.22	2.96	3.69	5.53	7.37	9.20	11.04	12.88	60
61	1.83	2.19	2.91	3.63	5.44	7.25	9.05	10.86	12.67	61
62	1.80	2.15	2.86	3.57	5.35	7.13	8.91	10.69	12.46	62
63	1.77	2.12	2.82	3.52	5.27	7.02	8.77	10.52	12.27	63
64	1.74	2.08	2.77	3.46	5.19	6.91	8.63	10.35	12.08	64
65	1.71	2.05	2.73	3.41	5.11	6.80	8.50	10.19	11.89	65
66	1.69	2.02	2.69	3.36	5.03	6.70	8.37	10.04	11.71	66
67	1.66	1.99	2.65	3.31	4.95	6.60	8.24	9.89	11.54	67
68	1.64	1.96	2.61	3.26	4.88	6.50	8.12	9.74	11.37	68
69	1.62	1.94	2.57	3.21	4.81	6.41	8.01	9.60	11.20	69
70	1.59	1.91	2.54	3.17	4.74	6.32	7.89	9.47	11.04	70
	50	60	80	100	150	200	250	300	350	

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
 EQUATION: $V = 2.2048 R + 0.0178$ (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND										Seconds
	Revolutions										
	3	5	7	10	15	20	25	30	40		
40	0.183	0.293	0.404	0.569	0.845	1.12	1.40	1.67	2.22	40	
41	0.179	0.287	0.394	0.556	0.824	1.09	1.36	1.63	2.17	41	
42	0.175	0.280	0.385	0.543	0.805	1.07	1.33	1.59	2.12	42	
43	0.172	0.274	0.377	0.531	0.787	1.04	1.30	1.56	2.07	43	
44	0.168	0.268	0.369	0.519	0.769	1.02	1.27	1.52	2.02	44	
45	0.165	0.263	0.361	0.508	0.753	0.998	1.24	1.49	1.98	45	
46	0.162	0.257	0.353	0.497	0.737	0.976	1.22	1.46	1.94	46	
47	0.159	0.252	0.346	0.487	0.721	0.956	1.19	1.43	1.89	47	
48	0.156	0.247	0.339	0.477	0.707	0.936	1.17	1.40	1.86	48	
49	0.153	0.243	0.333	0.468	0.693	0.918	1.14	1.37	1.82	49	
50	0.150	0.238	0.326	0.459	0.679	0.900	1.12	1.34	1.78	50	
51	0.147	0.234	0.320	0.450	0.666	0.882	1.10	1.31	1.75	51	
52	0.145	0.230	0.315	0.442	0.654	0.866	1.08	1.29	1.71	52	
53	0.143	0.226	0.309	0.434	0.642	0.850	1.06	1.27	1.68	53	
54	0.140	0.222	0.304	0.426	0.630	0.834	1.04	1.24	1.65	54	
55	0.138	0.218	0.298	0.419	0.619	0.820	1.02	1.22	1.62	55	
56	0.136	0.215	0.293	0.412	0.608	0.805	1.00	1.20	1.59	56	
57	0.134	0.211	0.289	0.405	0.598	0.791	0.985	1.18	1.57	57	
58	0.132	0.208	0.284	0.398	0.588	0.778	0.968	1.16	1.54	58	
59	0.130	0.205	0.279	0.391	0.578	0.765	0.952	1.14	1.51	59	
60	0.128	0.202	0.275	0.385	0.569	0.753	0.936	1.12	1.49	60	
61	0.126	0.199	0.271	0.379	0.560	0.741	0.921	1.10	1.46	61	
62	0.124	0.196	0.267	0.373	0.551	0.729	0.907	1.08	1.44	62	
63	0.123	0.193	0.263	0.368	0.543	0.718	0.893	1.07	1.42	63	
64	0.121	0.190	0.259	0.362	0.535	0.707	0.879	1.05	1.40	64	
65	0.120	0.187	0.255	0.357	0.527	0.696	0.866	1.04	1.37	65	
66	0.118	0.185	0.252	0.352	0.519	0.686	0.853	1.02	1.35	66	
67	0.117	0.182	0.248	0.347	0.511	0.676	0.840	1.01	1.33	67	
68	0.115	0.180	0.245	0.342	0.504	0.666	0.828	0.991	1.31	68	
69	0.114	0.178	0.241	0.337	0.497	0.657	0.817	0.976	1.30	69	
70	0.112	0.175	0.238	0.333	0.490	0.648	0.805	0.963	1.28	70	
	3	5	7	10	15	20	25	30	40		

Figure 37. Example of a standard current-meter rating table No. 2 for Price AA current meters with cat's-whisker and magnetic contact chambers.

Electromagnetic Current Meters

Electromagnetic current meters, with no moving parts, are commercially available for measuring point velocities. These meters are based on the principle that a conductor (in this case, water) moving through a magnetic field will produce an electric current. The velocity of the moving water can be related to the electric current produced, and the distortion created in the magnetic field. The electromagnetic meters can be accurately calibrated in a tow tank, similar to the calibration of mechanical meters; however, tests have shown that the electromagnetic meters are less accurate than the Price AA meters, especially at low velocities (less than about 0.5 ft/s). The Price AA meters also have less variance than the electromagnetic meters at all velocities. Advantages of the electromagnetic current meter are as follows: no moving parts; direct readout of velocity; and, in oblique flow, the velocity measured is normal to the measuring section when the meter is held normal to it.

Marsh-McBirney 2000

An electromagnetic current meter successfully used by the USGS for making discharge measurements is the Model 2000, produced by Marsh-McBirney. This meter, as shown in figure 38, is designed to mount on a standard round or top-setting wading rod. The meter is not designed for cable suspension.

A display meter, also shown in figure 38, shows a direct readout of the velocity. No conversion equation or table is necessary. The meter must be kept clean for accurate readings, and it is recommended that the rating be occasionally spot checked to verify that it is still accurate. This can be done in two ways. First, submerge the meter in a bucket of still water to verify the zero point of the rating. Second, place the meter in close proximity to a Price AA meter, in flowing water, to verify that it gives the same velocity reading. If there are differences, rate the electromagnetic meter again in the tow tank.



Figure 38. Marsh-McBirney Model 2000 electromagnetic flowmeter and display meter.

Ott Electromagnetic Current Meter

An Ott electromagnetic current meter is available; however, it has not been used extensively in the United States. The Ott meter, shown in figure 39, works in a manner similar to the Marsh-McBirney meter.



Figure 39. Ott electromagnetic current meter.

Acoustic Current Meters

Acoustic Doppler current meters, with no moving parts, are commercially available for measuring point velocities. These meters are based on the Doppler principle. The velocity of the moving water is measured using the transmitted and received signals from sound pulses reflecting off particles in the moving water column. These acoustic meters can be accurately calibrated in a tow tank, similar to the calibration of mechanical meters. Advantages of an acoustic Doppler current meter are as follows: no moving parts; direct readout of velocity; and ability to sense very low velocities less than the rated velocities in standard mechanical current meters.

Acoustic Doppler Velocimeter (ADV)

The SonTek/YSI FlowTracker handheld ADV ("FlowTracker" and "ADV" are used interchangeably in this chapter) is designed as an alternative to the Price AA and pygmy meters for wading discharge measurements. The FlowTracker operates at an acoustic frequency of 10 MHz and measures the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow. The magnitude of the phase change is proportional to the flow velocity. The phase difference can be positive or negative, allowing ADVs to measure positive and negative velocities. The FlowTracker measures the velocity at a rate of approximately 10 MHz, averages the data, and records 1-second velocity-vector data.

The maximum velocity the FlowTracker can measure is reduced when measuring flow that is not perpendicular to the transmitting transducer. The receiving transducers can measure a velocity range of only ± 1.15 m/s (3.77 ft/s). A velocity component placed directly toward or away from the receiving transducers larger than 1.15 m/s (3.77 ft/s) will result in erroneous velocities. Because of the geometric arrangement of the transmitting and receiving transducers, a velocity of 4.5 m/s flowing perpendicular to the transmitting transducer face will result in the maximum velocity towards a receiving transducer of 1.15 m/s (3.77 ft/s).

The FlowTracker probe is mounted to a standard top-setting wading rod with a special offset-mounting bracket (fig. 40). This bracket is designed to locate the FlowTracker probe at the front of the wading rod, with the sampling volume

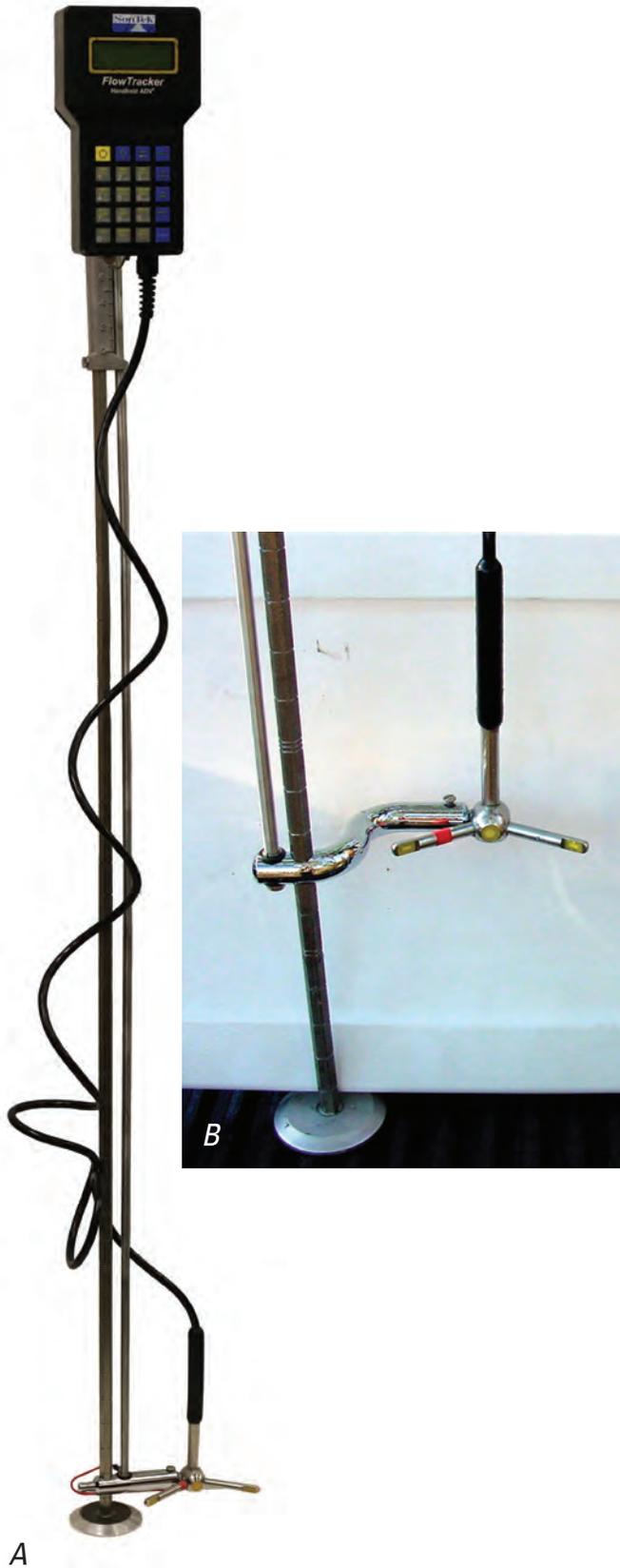


Figure 40. A, SonTek/YSI FlowTracker acoustic Doppler velocimeter (ADV) mounted on a standard top-setting wading rod and B, closer view of transmitting and receiving transducers and offset-mounting bracket.

about 2 in. (5 cm) to the right of the wading rod. Although the probe is inserted into the flow, the sampling volume is about 4 in. (10 cm) away from all physical parts of the probe, to minimize flow disturbance in the sampling volume.

FlowTrackers have several unique data-processing requirements because of their method of operation and some of the inherent limitations of the acoustic Doppler measurement technique. Unlike mechanical meters that use the momentum of the water to turn a propeller and directly measure the velocity of the water, the FlowTracker does not measure the velocity of the water. The FlowTracker measures the velocity of particles (sediment, small organisms, and bubbles) suspended in the flow, assuming that these particles travel at the same velocity as the water. Therefore, the quality of the measurement is dependent on the presence of particles within the sampling volume that reflect a transmitted signal. The FlowTracker records the signal-to-noise ratio (SNR), standard error of velocity (based on 1-second data), angle of the measured flow (relative to the x-axis of the FlowTracker probe), number of filtered velocity spikes, and a boundary quality-control flag. These velocity and quality-assurance data may be used to evaluate the measurement conditions. Few similar quality-assurance data are available for Price current-meter measurements.

Although a FlowTracker can measure within about 1.2 in. (3 cm) of a boundary, the velocity measurement might be affected by acoustic interference when the sampling volume is close to boundaries or underwater objects, even when the sampling volume is not directly on or past the boundary. At the start of each velocity measurement, if the probe detects nearby acoustic boundaries that could cause interference with the velocity measurement, a boundary adjustment is automatically made. The boundary adjustment attempts to overcome the possible interference by reducing the lag times of the acoustic signals transmitted by the FlowTracker, causing a reduction of the velocity range that can be measured. Any changes are noted in the boundary quality-control flag. Because the sampling volume is located about 4 in. (10 cm) from the transmitting transducer it can be difficult to ascertain the precise location of the sampling volume. If the sampling volume is on or past a boundary, the velocity data will be erroneous. Be careful to avoid boundaries while making measurements in depths less than 3.54 in. (9 cm), especially in channels with irregular bottoms.

Spikes in velocity data occur with any acoustic Doppler velocity sensor such as the FlowTracker. Spikes may have a variety of causes (for example, large particles in the flow, air bubbles, or acoustic anomalies). Velocity data from each FlowTracker measurement are evaluated to look for spikes. The FlowTracker spike filter is a variation on a method called “Tukey’s Outlier.” In this method, a histogram of each velocity component is calculated. The FlowTracker determines the lower quartile ($Q1$; 25 percent of samples are less than this value), the upper quartile ($Q3$; 75 percent of samples are less than this value), and the interquartile range ($IQR = Q3 - Q1$). If the IQR is less than 0.015 m/s (0.049 ft/s), IQR is set to

0.015 m/s (0.049 ft/s). Any value less than ($Q1-2*IQR$) or greater than ($Q3+2*IQR$) is considered a spike and is not used for mean-velocity calculations.

The FlowTracker measures magnitude and direction of velocity. The operator must keep the wading rod perpendicular to the tag line so that the pulse generated by the transmitter is parallel to the tag line, regardless of flow direction. To compute discharge, the FlowTracker uses the component of velocity perpendicular to the transmitting transducer and reports the flow angle from the FlowTracker's x-axis as a quality-control value. A flow angle measured by the FlowTracker may be the result of flow that is not perpendicular to the tag line, or a wading rod that is not being held perpendicular to the tag line (operator error). Flow angles of less than 20 degrees with small variations between verticals are not unusual. Large fluctuations of flow angles between verticals, however, may indicate a poorly measured cross section. If there is angular flow, and the wading rod is oriented with the flow, the velocity used and resulting discharge would be biased high. If the flow is truly perpendicular to the cross section, but the wading rod is erroneously held at an angle, the velocity and resulting discharge would be biased low. To avoid possible errors in the measured velocities, it is important that the operator always carefully and accurately aligns the wading rod.

Signal-to-Noise Ratio (SNR)

Adequate signal-to-noise ratio is needed to obtain an accurate measurement of the flow velocity. SNR is a measure of the strength of the reflected acoustic signal relative to the ambient noise level of the instrument. SNR is a function of the concentration and size distribution of the particles that reflect the acoustic signal. SNR is recorded for each beam with each 1-second sample. The manufacturer states that optimal SNR is 10 decibels (dB) or above (SonTek/YSI, 2002). USGS policy is that FlowTrackers should not be used for measuring discharge if the SNR for any single beam is less than 4 dB.

Speed of Sound

The accuracy of hydroacoustics instruments like the FlowTracker is dependent on an accurate speed of sound. The speed of sound is primarily a function of the temperature and salinity of the water. The FlowTracker has a built-in temperature sensor. To verify that the temperature sensor is working correctly, take an independent water-temperature measurement prior to each discharge measurement. If the FlowTracker

has been stored in an environment with a different ambient temperature from the water, the probe may need to be placed in the water for a period of time, allowing it to equilibrate with the water temperature. A 5°F error in temperature will result in approximately a 1-percent bias in the measured velocity. The speed of sound is also sensitive to salinity. A 5-part-per-thousand error in salinity would result in an approximate velocity bias of 1 percent, when used in saline environments like estuaries; therefore, the operator needs to measure the salinity and input the value into the FlowTracker.

Maintenance and Care

Although the built-in QCtest is reliable for detecting issues, a BeamCheck stores more system performance data and still may be needed to evaluate the unit in more detail when there is a potential issue.

QCtests and BeamChecks

- Perform a QCtest and store it with each measurement. When a QCtest is completed as part of a measurement, it will print out on the measurement summary.
- Complete a QCtest in flowing water with the sample volume away from any boundaries.
- Perform a BeamCheck if you notice any anomalies in the QCtest. Any failures in a QCtest require a BeamCheck.
- Perform a BeamCheck after any possible physical damage (drop, and so forth), firmware upgrade, or repair.

As stated previously, the FlowTracker is an acoustic Doppler velocimeter (ADV) that has been adapted to fit on a typical USGS streamgaging wading rod, developed by the USGS in cooperation with the SonTek/YSI Inc., and is widely used by the USGS. The FlowTracker has undergone extensive testing to evaluate differences between the FlowTracker performance and vertical-axis current meters (that is, Price AA, pygmy, and so forth).

The USGS Office of Surface Water, through the HIF, has put into place a process that will check and recalibrate each FlowTracker approximately every 3 years to ensure the quality assurance/quality control of this instrument in the measurement of the Nation's surface-water resources. For additional details, see Office of Surface Water Memorandum 2010.02 (2010).

Acoustic Digital Current Meter (ADC)

Another development that is a potential alternative to the Price AA and pygmy meters for wading discharge measurements is the Ott acoustic digital current meter (ADC) (fig. 41). The Ott ADC operates with two transducers at an acoustic frequency of 6 MHz, and measures the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow. The phase measurement is restricted to ± 180 degrees and uses a pulse scheme with two different time delays to resolve the phase ambiguity.

The velocity (V) is computed using the following formula:

$$V = \frac{c \times \Delta\Phi}{4 \times \pi \times \tau} \tag{19}$$

where V velocity (in distance per unit time),
 c speed of sound in water (in distance per unit time),

$\Delta\Phi$ computed phase difference, and
 τ time lag between pulses.

The Ott ADC uses a pulse-coherent technique. Transmitted pulses have a known lag time (τ). Backscatter echoes are amplified in the sensor head and then sent to the handheld display where they are digitized. A stable quartz oscillator controls the measurement sequence.

The Ott ADC has several unique data-processing requirements because of its method of operation and some of the inherent limitations of the acoustic Doppler measurement technique. Unlike mechanical meters that use the momentum of the water to turn a propeller and directly measure the velocity of the water, the Ott ADC, as with other acoustic Doppler current meters in use in the USGS and elsewhere, does not measure the velocity of the water. The Ott ADC measures the velocity of particles (sediment, small organisms, and bubbles) suspended in the flow, assuming that these particles travel at the same velocity as the

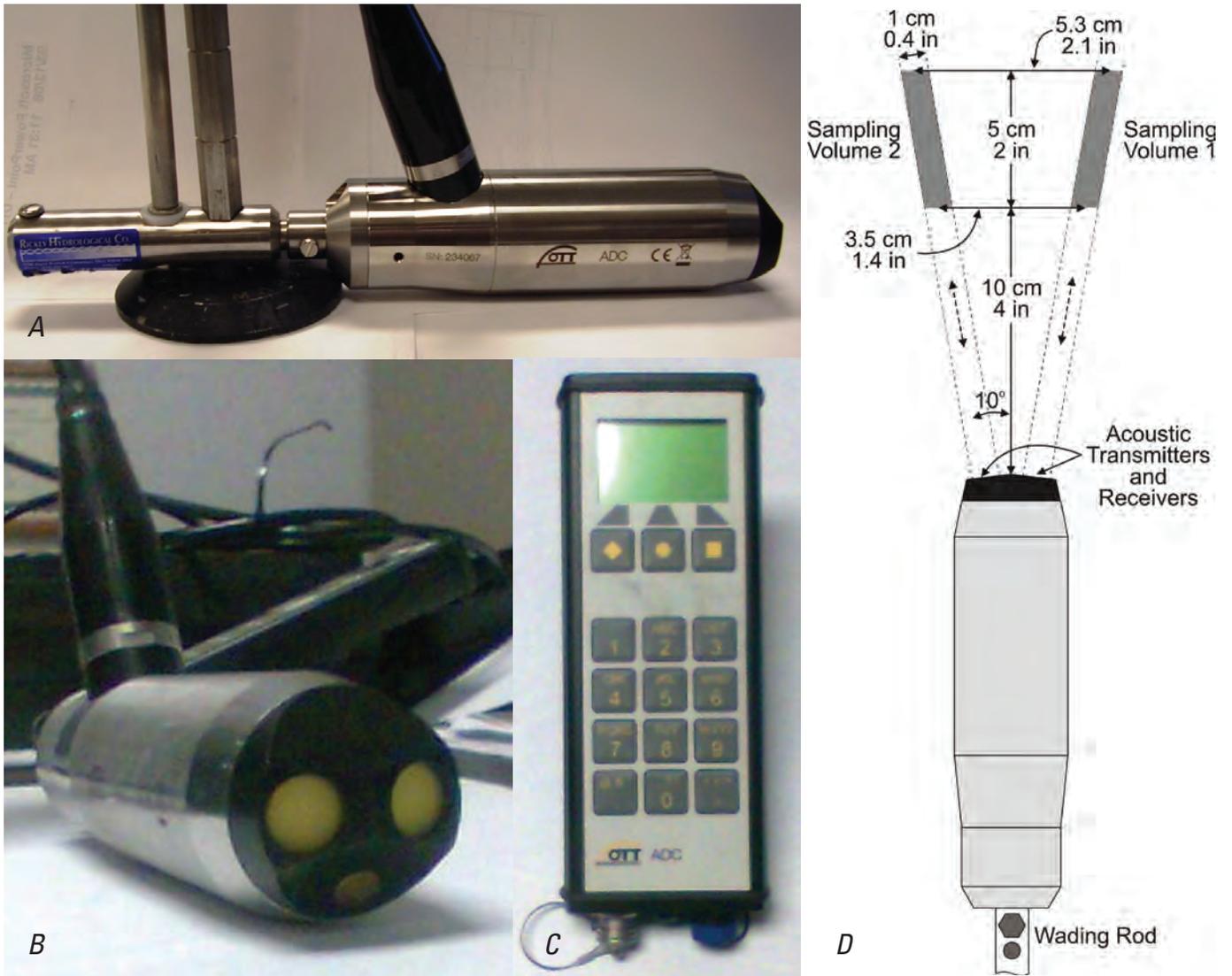


Figure 41. A, Ott acoustic digital current meter (ADC) mounted on a standard top-setting wading rod; B, closer view of transmitting and receiving transducers; C, ADC datalogger; and D, schematic of the sampling volume and transducers.

water. Therefore, the quality of the measurement is dependent on the presence of particles within the sampling volume that reflect a transmitted signal. In addition, the Ott ADC measures depth by using an absolute piezoresistive pressure cell with a range of 0 to about 16.4 ft (0–5 m). The pressure cell is located inside the probe and protected by the wading rod adapter, which is securely fastened with two screws. The hydrographer can estimate a depth without reading the top-setting rod.

Preliminary testing of the Ott ADC at the HIF indicates this technology has a lot of potential for use as an alternative to mechanical current meters.

Acoustic Doppler Current Profiler (ADCP)

The ADCP measures velocity magnitude and direction using the Doppler shift of acoustic energy reflected by material suspended in the water column, providing essentially a complete vertical profile of velocity.

Broadband, narrowband, and other pulse-to-pulse coherent ADCPs transmit pairs of acoustic pulses along a narrow beam from each of multiple transducers. As the pulses travel through the water column, they strike suspended sediment and organic particles (referred to as “scatterers”) that reflect some of the acoustic energy back to the ADCP. The ADCP receives and records the reflected pulses. The reflected pulses are separated by time differences (range gating) into successive volumes called “depth cells.” The frequency shift (known as the Doppler effect) is proportional to the velocity of the scatterers relative to the ADCP. The ADCP computes a velocity component along each beam, because the beams are positioned at a known angle from the vertical (usually 20 or 30 degrees) and in known horizontal orientations so that trigonometric relations can be used to compute three-dimensional water-velocity vectors for each depth cell. Therefore, the ADCP produces vertical profiles of velocity composed of water speeds and directions at regularly spaced intervals, vertical profiles of velocity, discharge profiles, and a wealth of information for a discharge measurement (fig. 42).

The Broadband ADCPs (such as the Teledyne RD Instruments Rio Grande ADCPs) use phase-coded pulses, such that many independent measurements of velocity can be made by a single Broadband pulse of the same length as a narrowband pulse. These independent measurements are averaged to produce a velocity with a lower uncertainty than would be possible with a single measurement. Narrow-band systems (such as the SonTek/YSI RiverSurveyor S5 and M9) typically compensate for this characteristic by pinging faster (sending more pulses per second, up to 20 Hz) and reporting a velocity based on the average of many pulses with a typical velocity output of 1 Hz.

Currently, the most common main external components of an ADCP are a transducer assembly and a pressure case.

Commonly, the transducer assembly consists of three to nine transducers that operate at a fixed, ultrasonic frequency, typically 300 to 3,000 kilohertz (kHz). The transducers are horizontally spaced around the transducer assembly; all transducers have the same fixed angle from the vertical, referred to as a “beam angle,” that is typically between 20 and 30 degrees. The transducer assembly may have a convex or concave configuration or, in the case of the phased array, an essentially flat surface. The pressure case is attached to the transducer assembly. Examples of several different ADCPs used in the USGS are shown in figure 43.

When an ADCP is deployed from a moving boat, it is connected by cable to a power source and by cable or radio modem to a portable microcomputer. The computer is used to program the instrument, monitor its operation, and collect and store the data. For a detailed description of how an ADCP measures velocity and computes discharge, and detailed instruction in the use of ADCP technology with reference to moving boats, see Mueller and Wagner (2009).

Midsection Method With an ADCP

When an ADCP is deployed to perform a midsection method discharge measurement, most best practices used for mechanical-meter discharge measurements still apply. These practices, including site selection, are well documented in Rantz and others (1982). The midsection method with an ADCP is similar to the midsection method used for mechanical-meter discharge measurements and involves measuring the channel area and water velocities of a stream at a cross section; however, instead of point measurements of velocity, with this method, the average velocity is obtained by profiling the velocity in the water column at each section. The channel is divided into a number of vertical subsections. Most natural channels must be divided into 20 or 30 subsections to adequately characterize their irregular geometry. The depth and average velocity are measured at each subsection and are applied to a subarea whose width extends halfway to the preceding and following observation points. The area of each subsection is determined by directly measuring width and depth. The average water velocity in each subsection is estimated using the measured velocity at elected locations in the vertical. The total discharge within the stream is the sum of the individual subsection discharges.

Additional details and in-depth discussion of ADCP technology, methodology, and quality assurance and quality control can be found in USGS publications by Simpson and Oltmann (1993), in Lipscomb (1995), Morlock (1996), Oberg and others (2005), and Mueller and Wagner (2009). The ADCP method is a relatively new and evolving technology, and as a result, there are ongoing changes to the hardware, software, and firmware.

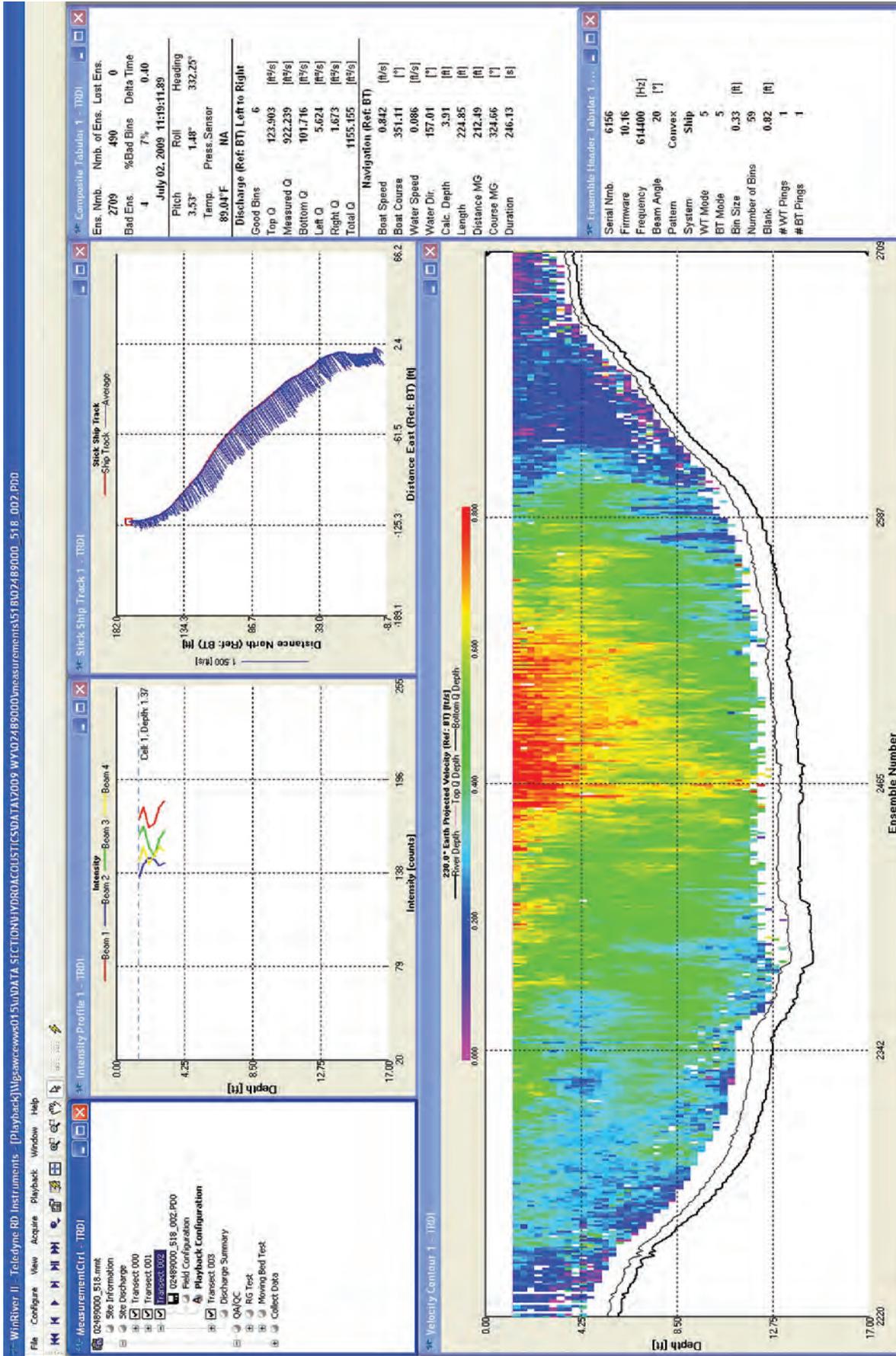


Figure 42. Screen capture of an ADCP measurement of discharge for the Pearl River near Columbia, MS (02489000).



Figure 43. Examples of acoustic Doppler current profilers (ADCPs) used to measure discharge at gaging stations; A, Teledyne RD Instruments 600 kHz Rio Grande ADCP; B, Teledyne RD Instruments 600 kHz RiverRay phased array ADCP, and C, closeup view of phased array ADCP; D, SonTek/YSI RiverSurveyor S5; E, SonTek/YSI RiverSurveyor M9; and F, Teledyne RD Instruments StreamPro ADCP.

Optical Current Meters

An optical current meter, as shown in figure 44, is a stroboscopic device designed to measure surface velocities in open channels without immersing equipment in the stream. The optical current meter is used principally in measurements of surface velocity during floods when it is impossible to use streamgaging equipment that requires placement in the water, because of extremely high velocities and high-debris content in the stream. Use of this technology and other technologies, such as radar, deserves further investigation in the measurement of discharge using surface velocities.



Figure 44. Hydrographer using an optical current meter to measure surface velocity.

Sounding Equipment

Sounding (determination of depth) is commonly done mechanically; the equipment used depends upon the type of measurement being made. Measure depth and position in the vertical with a rigid rod or by a sounding weight suspended from a cable. The cable is controlled either by a reel or by a handline. A sonic sounder is also available, but it is usually used in conjunction with a reel and a sounding weight. The various equipment that can be used for sounding is described in the following paragraphs. In addition, ADCPs can sound depths using sophisticated algorithms that may have global positioning features and capabilities. Mueller and Wagner (2009) discuss ADCP sounding in more detail.

Top-Setting Wading Rods

The two types of wading rods commonly used are the top-setting rod and the round rod. The top-setting rod is preferred because of the convenience in setting the meter at the proper depth and because the hydrographer can keep his hands dry.

The top-setting wading rod, as shown in figure 45, has a $\frac{1}{2}$ -in. hexagonal main rod for measuring depth and a $\frac{3}{8}$ -in. diameter round rod for setting the position of the current meter.

The rod is placed in the stream so the base plate rests on the streambed, and the depth of water is read on the graduated main rod. When the setting rod is adjusted to read the depth of water, the meter is positioned automatically for the 0.6-depth method, as shown in figure 46. The 0.6-depth setting is the setting measured down from the water surface. This setting is the same as the 0.4-depth position when measured up from the streambed. When the depth of water is divided by 2, and this value is set on the setting rod, the meter will be at the 0.8-depth position from the water surface. When the depth of water is multiplied by 2, and this value is set, the meter will be at the 0.2-depth position from the water surface.

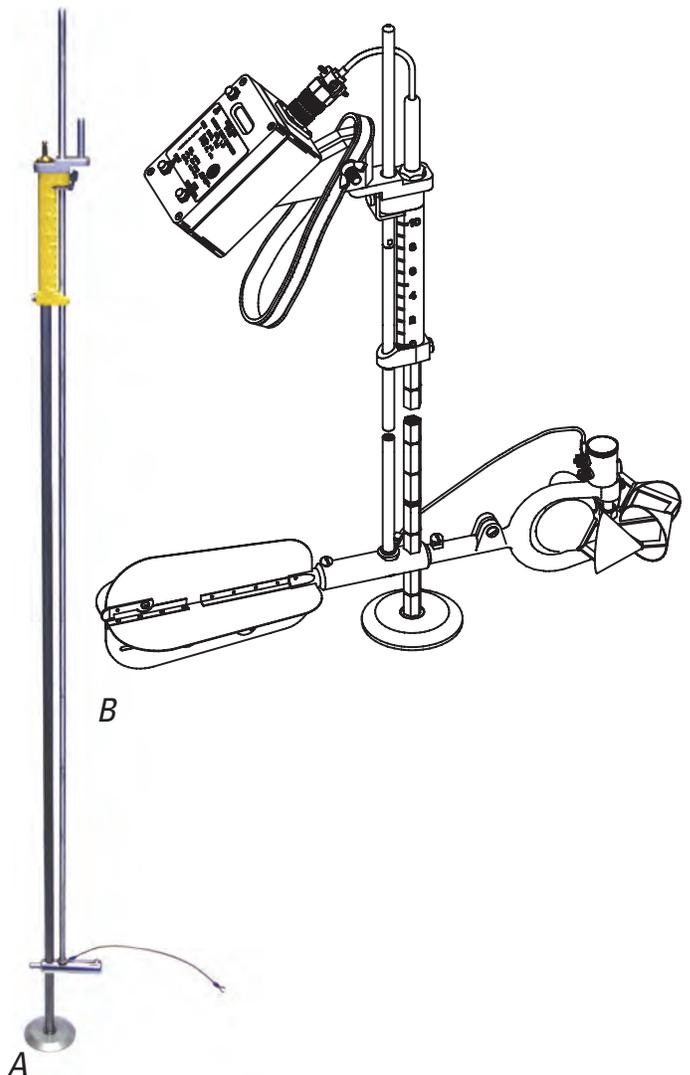


Figure 45. *A*, Top-setting wading rod and *B*, schematic of a top-setting wading rod with Price AA current meter and current-meter digitizer (CMD) attached.



Figure 46. Closeup view of setting scale on handle of top-setting wading rod.

Round Wading Rods

The round wading rod, as shown in figure 47, consists of a base plate, lower section, sliding support, three or four intermediate sections, and a rod end (not essential). The parts are assembled as shown in figure 48. The meter is mounted on the sliding support and is set at the desired position on the rod by sliding the support. The round rod can be assembled into various lengths using the 1-ft sections, and it is easy to store and transport when disassembled.



Figure 47. Parts for the round wading rod.



Figure 48. Round wading rod with Price AA current meter attached.

Winter-Style Suspension Wading Rods

Measurements made under ice cover should use the WSCan winter sounding rods, either in the ½- or 1-in.-diameter versions. These rods are available in sections so that the desired length can be assembled. A special foot fits the lower section, and the rods will accommodate the winter-style current-meter yoke, as shown in figure 49.

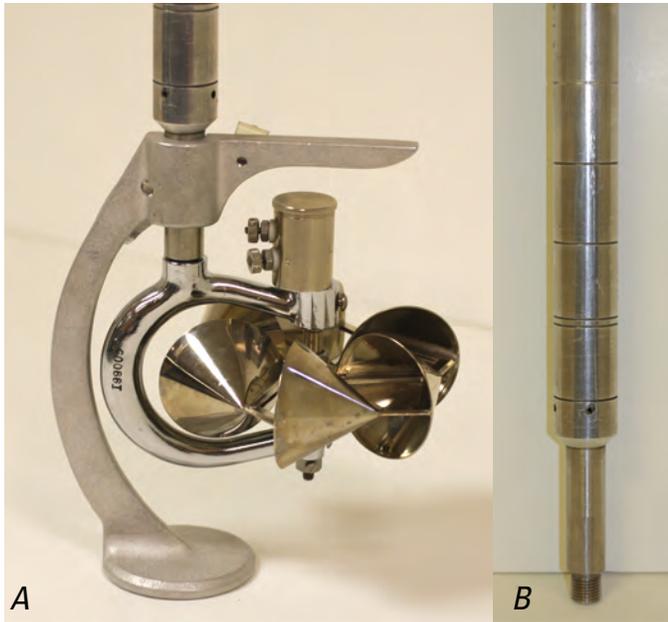


Figure 49. Water Survey Canada winter-style round 1-inch suspension rod and meter: *A*, with Price AA meter in a winter-style yoke attached and *B*, closer view of round 1-inch diameter suspension rod.

Sounding Weights

If a stream is too deep or too swift to wade, the current meter is suspended in the water from a boat, bridge, or cableway. A sounding weight is suspended below the current meter to keep it stationary in the water. The weight also prevents damage to the meter when the assembly is lowered to the streambed.

The sounding weights currently used are the Columbus weights, commonly called the C type, and are shown in figure 50. The weights are streamlined to offer minimum resistance to flowing water. The weights are available in 15-, 30-, 50-, 75-, 100-, 150-, 200-, and 300-pound sizes. Each weight has a vertical slot and a drilled horizontal hole to accommodate a weight hanger and securing pin.



Figure 50. Columbus C-type sounding weights (15 through 300 pounds).

Hanger Bars

The weight hanger is attached to the end of the sounding line by a connector. The current meter is attached to the hanger bar beneath the connector, and the sounding weight is attached to the lower end of the hanger bar.

There are three types of weight hanger bars, as shown in figure 51:

1. The Columbus or C type, $\frac{1}{8} \times \frac{3}{4} \times 12$ in. (for weights up to 150 pounds);
2. Heavy weight, $\frac{1}{8} \times \frac{3}{4} \times 18$ in. (for 200- and 300-pound weights);
3. Heavy weight, $\frac{1}{8} \times 1\frac{1}{2} \times 18$ in. (for 200- and 300-pound sounding weights that have the slots properly extended to accommodate a ½-in. wide hanger bar).



Figure 51. Sounding weight hanger bars and hanger pins.

The Columbus hanger bar contains three holes in order to properly position the meter. The hanger screw of the current-meter yoke is placed through the bottom hole to support the meter when a 30-pound sounding weight is used. The center of the meter cups is then 0.5 ft above the bottom of the weight. This arrangement is designated as 30 C .5, which means that a 30-pound Columbus weight is being used and the center of the meter cups is 0.5 ft above the bottom of the weight. The hanger screw goes through the middle hole when 15- or 50-pound weights are used. The designations for these arrangements are 15 C .5 and 50 C .55. The hanger screw goes through the upper hole when 50-, 75-, 100-, and 150-pound weights are used. The designations for these arrangements are 50 C .9, 75 C 1.0, 100 C 1.0, and 150 C 1.0. Each of the two heavy-weight hangers has only one hole for the hanger screw of the meter. The designations for these arrangements are 200 C 1.5 and 300 C 1.5.

Weight-hanger pins of various lengths, as shown in figure 51, are available for attaching the sounding weight to the hanger bar. The stainless steel pins are threaded on one end to screw into the hanger bar and slotted on the other.

Sounding Reels

Several different types of sounding reels are available for use with the Columbus C-type weights. In general, a sounding reel has a drum for winding the sounding cable, a crank-and-ratchet assembly for raising and lowering the weight or holding it in any desired position, and a depth indicator. Table 11 contains detailed information on each of the five most commonly used reels.

The A-pack reel, as shown in figure 52, is light, compact, and ideal for use at cableway sites a considerable distance from the highway. It can also be used on cranes, bridge boards, and boat booms.



Figure 52. A-pack reel.

Table 11. Sounding reel data.

Reel	Sounding cable	Cable diameter, in inches	Drum circumference, in feet	Cable capacity, in feet	Maximum weight, in pounds	Depth indicator	Brake	Type of operation
A-pack	Ellsworth	0.084	1	45	50	Counter	No	Hand.
Canfield	Single conductor ¹	.0625	1	45	50	Counter	No	Hand.
A-55	Ellsworth	.084 .10	1	95 80	50 100	Self computing	No	Hand.
B-56	Ellsworth	.10 .125	1.5	144 115	150 200	Self computing	Yes	Hand or power.
E-53	Ellsworth	.10 .125	2	206 165	150 300	Self computing	Yes	Power.

¹Some Canfield reels have been converted to double-conductor cable but most of them are still used as single-conductor reels.

The Canfield reel, as shown in figure 53, is also compact with uses similar to that of the A-pack reel. The Canfield reel is not available from the HIF, and must be obtained from Leupold and Stevens Instruments, Inc.

The A-55 reel is for general purpose use with the lighter sounding weights, as shown in figure 54.

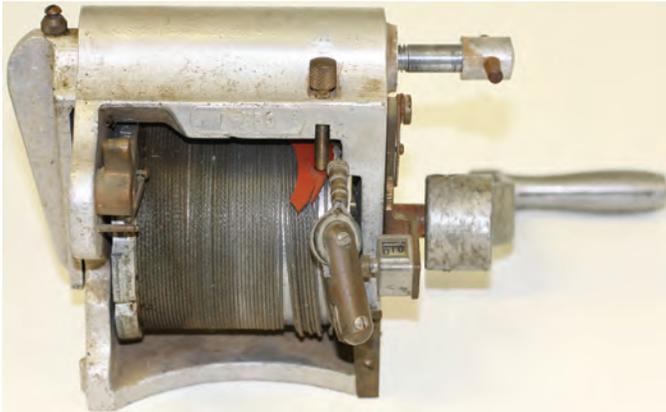


Figure 53. Canfield reel.

The B-56 reel (a major modification of the B-50 reel) can handle all but the heaviest sounding weights and has the advantage that it can be used with a hand crank or power equipment, as shown in figure 54.

The E-53 reel is the largest reel commonly used for current-meter measurements. This reel will handle the heaviest sounding weights and is designed exclusively for use with power equipment. It has a hand crank for emergency use, as shown in figure 55.



Figure 55. E-53 reel.

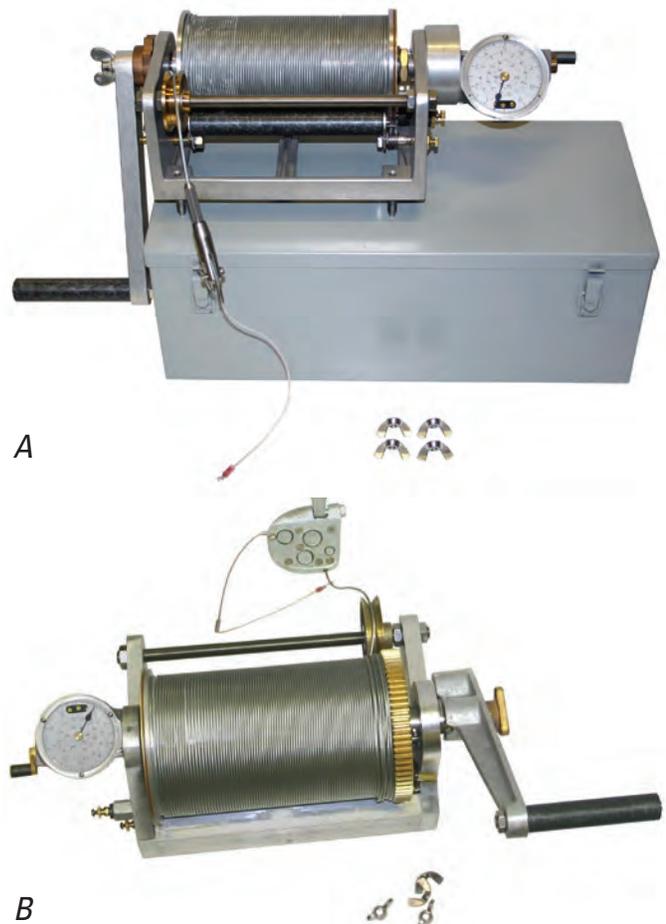


Figure 54. A, A-55 reel and B, B-56 reel.

Sounding Cable

Ellsworth reverse-lay two-conductor stranded cable is normally used on all sounding reels, except the single-conductor Canfield reel, which uses galvanized steel aircraft cord. Ellsworth cables are normally available in 0.084-, 0.100-, and 0.125-in. diameters. It is important to use the appropriate size cable-laying sheave on the reels.

For safety purposes, when measuring floods, it is important to connect the sounding cable to the sounding reel in such a way that the cable will break in the event that heavy debris is caught and cannot be released. The cable will usually unwind (pay out) from the sounding reel until it reaches its end, at which point there is danger to the equipment and the hydrographer unless the cable is cut or breaks. Precut some of the cable strands when installing the cable on the reel so that the remaining strands will break when the load reaches a specified limit. Table 8 provides information about cable strength and number of strands to cut to provide the necessary safety margin. Complete instructions for making the cable installation are given in a HIF technical information sheet dated April 1999.

Connectors

A connector is used to join the end of the sounding cable to the sounding-weight hanger. The three types of connectors generally used are types B, C1, and pressed sleeve, as shown in figure 56. The type B connector is used with A-55, B-56, and E-53 reels. The C1 connector is used with the A-pack and Canfield reels, although the pressed-sleeve connector can be used on these reels. The pressed-sleeve connector is also used on handlines.

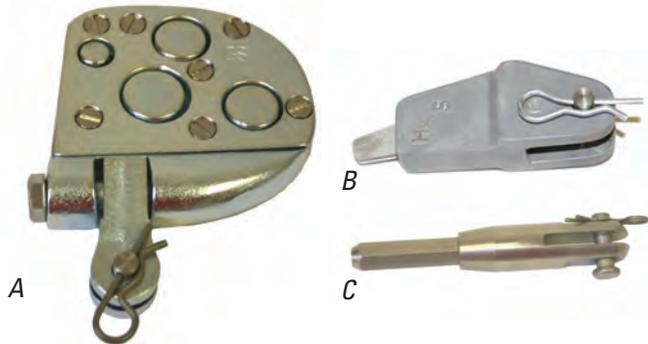


Figure 56. Connectors for attaching sounding cable to sounding-weight hanger; A, Type B; B, Type C1; and C, pressed sleeve.

Depth Indicators

A computing depth indicator, as shown in figure 57, is used on the A-55, B-56, and E-53 reels. The stainless-steel indicator is less than 3 in. in diameter and has nylon bushings that do not require oil. The main dial is graduated in feet and tenths of a foot from 0 to 10 ft. The depth is indicated by a pointer. Tens of feet are read on a numbered inner dial through an aperture near the top of the main dial.

The main dial has a graduated spiral to indicate directly the 0.8-depth position for depths up to 30 ft.

The A-pack and Canfield reels, shown in figures 52 and 53, are equipped with counters for indicating depths.



Figure 57. Computing depth indicator.

Handlines

A handline, shown in figure 58, is a device used for making discharge measurements from bridges using a 15- or 30-pound sounding weight. The advantages of using the handline are that it is easy to set up, it eliminates the use of a sounding reel and supporting equipment, and it reduces the difficulty in making measurements from bridges, which have interfering members, such as trusses. The disadvantages of using the handline are that there is a greater possibility of making errors in determining depth because of slippage of the handline, measuring scale, or tape, and it requires great physical exertion, especially in deep streams. Handlines can be used from cable cars, but this is not recommended because of the disadvantages mentioned above.

Ellsworth cable is recommended for handlines because of its flexibility and durability. Two-conductor electrical service cord is used between the headset connector and the handline reel.

The pressed-sleeve connector or the C1 connector is used on handlines because they are lighter in weight than the type B connector, yet strong enough for the sounding weights used with handlines.



Figure 58. Handline.

Power Unit

Power units, as shown in figure 59, are available for the B-56 and E-53 reels to raise and lower the sounding weight and meter. The power unit can be used with 6-, 12-, 18-, or 24-volt batteries.



Figure 59. Power units for sounding reels; *A*, J & H Single Speed Power Drive and *B*, USGS Variable Speed Reel Drive System.

Sonic Sounder

A commercial, compact, portable sonic sounder has been adapted to measure stream depth. The sounder is powered by either a 6- or 12-volt storage battery and will operate continuously for 10 hours on a single battery charge. Three recording speeds are available—36, 90, and 180 in. per hour. Four operating ranges—0 to 60 ft, 60 to 120 ft, 120 to 180 ft, and 180 to 240 ft—allow intervals of 60 ft of depth. The sounder is portable, weighing only 46 pounds. The depth recorded is from the water surface to the streambed. The transducer has a narrow beam angle of 6 degrees, which minimizes errors on inclined streambeds and allows the hydrographer to work close to piers or other obstructions.

Measurements can be made with this equipment without lowering the meter and weight to the streambed. As soon as the weight is in the water, the depth will be recorded. The meter can then be set at the 0.2 depth, or just below the water surface where a velocity reading is obtained. Then a coefficient is applied to convert measured velocity to the mean in the vertical.

Temperature change affects the sound propagation velocity, but this error is limited to about plus or minus 2 percent in freshwater. This error can be eliminated completely by adjusting the sounder to read correctly at a particular average depth determined by other means.

Cableway Equipment

The USGS cableway provides a track for the operation of a manned cable car from which the hydrographer makes a current-meter measurement. Most cableways have a clear span of 1,000 ft or less, although a few structures have been built with clear spans approaching 2,000 ft. The design and construction of cableways are described in detail by Wagner (1995).

Cable cars provide a movable platform from which the hydrographer, sounding reel, and other necessary equipment are supported. The newer versions of these cable cars are fabricated from aluminum, and have a standard follower brake and integral-reel mounts, which will accept all standard sounding reels, including battery-powered reels. Cable cars can also be equipped with the Sandpoint type cable-car brake, which allows the cable car to be slowed or stopped. Both sitdown and standup types of manually propelled cable cars are used in streamgaging, as shown in figures 60 and 61, and have space for two people to work. Some older cable cars still in use are fabricated partially from wood, may or may not have permanent reel mounts, and may have space for only one person.

Manned cable cars are moved from one point to another on the cableway by means of cable-car pullers, as shown in figure 62. The standard car puller is an aluminum-cast handle with a snub attached. The snub, usually four-ply belting, is placed between one of the car sheaves and the cable to prevent movement of the car along the cable. A second type of puller, also shown in figure 62, is used when a car is equipped with a follower brake. A third type, the Colorado River cable-car



Figure 60. Sit-down cable car.



Figure 61. Stand-up cable car.



Figure 62. Cable-car pullers: *A*, with belt and *B*, with follower brake.

puller, is the same in principle as the puller used on cars equipped with a follower brake.

Power-operated cable cars, such as the battery-powered car shown in figure 63, are available for extremely long spans or other special situations where extensive streamgaging and monitoring is required. The power assist on these cable cars is also utilized to operate a type E sounding reel.

Unmanned, remotely operated cable carriages, such as the Hydrological Services Hornet, are used for discharge measurements as well as for sediment sampling. The cable carriage and sounding equipment can be remotely operated from the stream bank, as shown in figure 64. They are used in areas where it is impossible to wade, where no bridges are available, and where it is not practical to build or maintain a manned cableway.

Unmanned cableways are used more in Europe than in the United States, but are becoming more common in the United States. These bank-operated cableways have obvious benefits in safety and convenience (fig. 65). Both permanent and portable bank-operated cableways are becoming more useful in the measurement of discharge, especially for more narrow streams, generally 300 ft or less in top-bank width.



Figure 63. Battery-powered cable car.



Figure 64. Remotely operated Hydrological Services Hornet cable carriage with ADCP and trimaran used by the USGS.



Figure 65. Bank-operated cableway.

Bridge Equipment

Streamflow measurements are frequently made from a bridge. The meter and sounding weight can be supported by a handline, a bridge board, or by a sounding reel mounted on a crane. An ADCP mounted on a tethered craft can also be deployed from a bridge. Tethered ADCP craft are rapidly becoming the prevalent means of measuring discharge from a bridge.

Handlines and Bridge Boards

A handline, as described in a previous section of this chapter, is the simplest form of bridge-measuring equipment. Used extensively in the 20th century, it does not require any separate reels or handling equipment; however, it can only be used with light sounding weights, such as the 15- and 30-pound size. It also requires that depth be measured with tags, and a tape or measuring stick.

A bridge board is a portable platform made from wood or metal upon which a small reel can be mounted. Bridge boards may be used with an A-pack, A-55, or B-56 sounding reel and weights up to 75 pounds. A bridge board is usually about 6 to 8 ft long, with a sheave at one end over which the meter cable passes, and a reel seat near the other end. The board is placed on the bridge rail so that the force exerted by the sounding weight suspended from the reel cable is counterbalanced by the weight of the sounding reel. The bridge board may be hinged near the middle to allow one end to be placed on the sidewalk or roadway. Figure 66 shows a bridge board in use.



Figure 66. Measuring from a bridge with a bridge board.

Portable Cranes

Two types of hand-operated portable cranes are the type A for weights up to 100 pounds, and the type E for weights greater than 100 pounds. The type A crane mounts on a three-wheel or four-wheel base or truck, and the type E crane mounts on a four-wheel base or truck. Cranes can be easily moved by hand along the sidewalk or floor of the bridge. Figure 67 shows a type A crane mounted on a three-wheel base, and figure 68 shows a type E crane mounted on a four-wheel base.

Any of the reels described in table 11 may be used on either of the portable cranes; however, the power-driven reels (B-56 and E-53) are used only with the Type E crane. Various combinations of cranes, bases (trucks), and reels are possible.



Figure 67. Type A crane mounted on a three-wheel base.



Figure 68. Type E crane mounted on a four-wheel base.

All cranes are designed so that the crane can be tilted forward over the bridge rail far enough for the meter and weight to clear most rails and be lowered to the water. Where bridge members obstruct passage of the crane along the bridge, the weight and meter can be raised and the crane can be tilted back to pass by the obstruction.

Use cast-iron counterweights weighing 60 pounds with four-wheel-base cranes. The number of such weights needed depends upon the size of sounding weight being supported, the depth and velocity of the stream, and the amount of debris being carried by the stream.

Use a protractor on the outer end of cranes to measure the angle the sounding line makes with the vertical when the weight and meter are dragged downstream by high-velocity water. The protractor is a graduated circle clamped to an aluminum plate. A plastic tube, partly filled with colored antifreeze (ethylene glycol), is the protractor index. This tube is fitted in a groove between the graduated circle and the aluminum plate. A stainless-steel rod is attached to the lower end of the plate to ride against the downstream side of the sounding cable. The protractor will measure vertical angles from -25 degrees to +90 degrees. Figure 69 is a close-up view of a protractor mounted at the outer end of the boom.

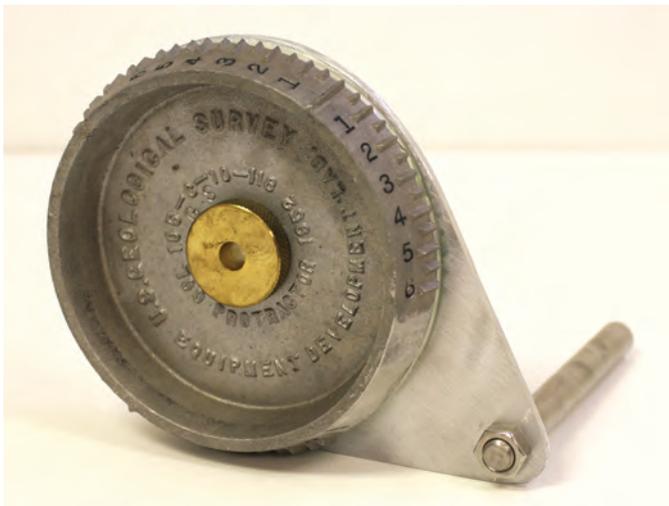


Figure 69. Protractor used for measuring vertical angles.

Power-Driven Cranes

Many special arrangements for measuring from bridges have been devised to suit a particular purpose. Vehicle-mounted cranes are often used for measuring from bridges over larger rivers, as shown in figure 70. Monorail streamgaging cars have also been developed for large rivers. The car is suspended from the substructure of bridges by means of I-beams.

Tethered Craft

The USGS, in cooperation with manufacturers, continues to test and refine tethered-platform designs for measuring streamflow. Platform specifications have been developed for



Figure 70. Vehicle-mounted, power-driven crane.

radio-modem telemetry of acoustic Doppler current profiler (ADCP) data, potential platform-hull sources have been investigated, and many hull configurations have been tested and evaluated.

Platforms, which included a variety of hull configurations, were tested for drag and stability at the USGS Hydraulic Laboratory tow tank and at a field site below a reservoir. The testing indicated that trimaran designs provided the best all-around performance under a range of conditions. The trimaran designs house the ADCP in the center hull. Waterproof radio modems that operate at 900 MHz are used to communicate wirelessly with instruments at high-baud rates.

A tethered-platform design with a trimaran hull, and 900-MHz radio modems, are commercially available from several vendors. Continued field use has resulted in USGS procedures for making tethered-platform discharge measurements, including methods for tethered-boat deployment, moving-bed tests, and measurement of edge distances. Figure 71 shows a tethered craft ADCP in wide usage in the USGS (Mueller and Wagner, 2009; Rehmel and others, 2003).



Figure 71. Measuring with a tethered ADCP, DGPS, and trimaran.

Boat Equipment

There are five basic types of boat measurements: the manual stationary boat, the manual moving boat, the automatic moving boat, the ADCP moving boat, and the remote-controlled ADCP moving boat. Equipment requirements for each of these boat measurement types are described in the following paragraphs.

Manual Stationary Boat

The manual stationary boat method uses a boat as a platform for the hydrographer and the sounding equipment. The boat is attached to a tag line or cable to stabilize it at each vertical where soundings are made. The heavy-duty tag lines required for boat measurements are described in a previous section of this chapter.

Special equipment assemblies, as shown in figure 72, are necessary to suspend the meter from the boat if the depths do not allow using rod suspension. A crosspiece spanning the boat is clamped to its sides, and a boom attached to the center of the crosspiece extends out over the bow. The crosspiece is equipped with a guide sheave and clamp arrangement at each end to attach the boat to the tag line, and makes it possible to slide the boat along the tag line from one station to the next. A small rope can be attached to these clamps so that in an emergency a tug on the rope will release the boat from the tag line. The crosspiece also has a clamp that prevents lateral movement of the boat along the tag line during readings. The boom consists of two structural aluminum channels, one telescoped within the other to permit adjustments in length. The boom is equipped with a reel plate on one end and a sheave over which the meter cable passes. The sheave end of the boom is designed so that by adding a cable clip to the sounding cable a short distance above the connector, the sheave end of the boom can be retracted when the meter is raised out of the water. The raised meter is easy to clean and is in a convenient position when not being operated.



Figure 72. Manual stationary-boat equipment assembly.

All sounding reels fit the boat boom, except the A-pack and the Canfield, which can be made to fit by drilling additional holes in the reel plate on the boom.

In addition to the equipment already mentioned, the following items are needed for making boat measurements:

1. A stable boat big enough to support the hydrographers and equipment;
2. A motor that can easily move the boat against the maximum current in the stream;
3. A pair of oars for standby use;
4. A personal floatation device (PFD) for each hydrographer; and
5. A bailing device.

Manual Moving Boat

Equipment requirements for the manual moving boat method of making a discharge measurement are described in detail by Smoot and Novak (1969); they are not described in this chapter. In summary, the manual moving-boat method requires a sonic sounder, a vane with indicator, a special current meter, and an easily maneuverable small boat. The manual moving-boat method is seldom used since the advent of the ADCP moving-boat method, which is described below.

Automatic Moving Boat

The automatic moving-boat method is similar to the manual moving-boat method, except that all readings of depth, velocity, angles, and distance are recorded automatically by onboard computer equipment. Equipment requirements are more complex in order to enable the automatic sensing and recording.

Like the manual moving-boat method, the automatic moving-boat method is seldom used since the advent of the ADCP moving-boat method.

ADCP Moving Boat

Currently, the ADCP moving-boat method is the most common moving-boat method in the USGS. All readings of depth, velocity, angles, and distance are recorded to a laptop or PDA and the discharge measurement is computed using ADCP software and input from the hydrographer.

As shown in figure 73, described in other sections of this chapter, and in depth by Mueller and Wagoner (2009), ADCP moving-boat measurement techniques have almost entirely superseded the automatic moving method.

Remote-Controlled ADCP Moving Boat

There are commercially available unmanned, remote-controlled craft with ADCPs used by the USGS and others for the measurement of discharge where a manned boat or tethered boat may not be feasible. Similar to but smaller than the ADCP moving-boat, these remote-controlled craft typically come with self-contained motors and a remote-controlled system for driving the boat across a stream or river. See Mueller and Wagner (2009) for an in depth discussion of remote-controlled ADCP moving boat discharge measurements.



Figure 73. ADCP equipment mounted and operated on *A*, a moving boat and *B*, a tethered platform.

Electronic Field Notebooks and Personal Digital Assistants (PDAs)

Recent developments in electronics have produced commercially available electronic field notebooks (EFNs) and personal digital assistants (PDAs), designed specifically for the purpose of recording field notes while making a discharge measurement (fig. 74). The PDAs are also designed for other field procedures, including discharge-measurement data collection and processing, station inspection, differential-level survey notes, and water-quality data collection and equipment calibration. The USGS commonly uses the Surface Water Measurements and Inspections (SWAMI) program with a PDA. The program can be used to record discharge measurements, inspections, differential-level surveys, and other field measurements. This software provides an efficient means of collecting field data (fig. 2C) and has been specifically designed to interface with the USGS NWIS.

The recording process is semiautomatic. Basic information and data still must be entered manually for measurements of stream depth, stationing, horizontal angle of flow, equipment, and other basic data.

EFNs automatically count meter revolutions and elapsed times, and make the conversion to stream velocity. They also assist the hydrographer with certain tasks, such as locating each subsection so that no more than 10 percent of the total flow will be included in each subsection. The notebook makes all of the measurement calculations to obtain the final discharge, and to summarize all pertinent items of the measurement.

The EFNs and PDAs can store many discharge-measurement reports. The EFN and (or) PDA reports for a discharge measurement are similar to the paper note sheets used for manual note keeping. A header, similar to the paper “front sheet,” contains site information, equipment information, and a summary of measurement data. The report also contains



Figure 74. Personal digital assistants (PDAs) and electronic field notebooks (EFNs), clockwise from the top: *A*, the Trimble Juno SB PDA with GPS, Bluetooth, and Parani Serial Adapter; *B*, the Trimble Nomad 800 GL PDA with GPS and Bluetooth; *C*, the Trimble Recon PDA without GPS; *D*, the JBS Instruments Aquacalc Pro Discharge Measurement Computer; and *E*, the Hydrological Services Current Meter Counter Signal Processor with Bluetooth (CMCsp).

complete measurement data, similar to the paper “inside notes,” for all of the individual subsections. In addition, the report contains various warning flags and quality-control information. Complete reports for each discharge measurement can be downloaded to a computer for viewing, printing, and other analysis.

One EFN widely used within the USGS is the Aquacalc Pro Discharge Measurement Computer (Aquacalc) by JBS Instruments. The Current Meter Counter Signal Processor (CMCsp) by Hydrological Services is used in concert with a PDA to measure discharge with a mechanical current meter, as shown in figure 74. The Aquacalc and the CMCsp will work with the cat’s-whisker-, magnetic-, and optic-contact chambers on the Price current meters. As with all EFNs, care should be taken to avoid false counting of meter revolutions when measuring low velocities with mechanical meters that have a cat’s-whisker-contact chamber.

PDA’s are manufactured by many computer companies in the United States and abroad. Several are considered reliable and have been successfully field tested. At this writing, the PDA can interface with most of the ADCPs and electronic data loggers used by the USGS.

Miscellaneous Equipment and Personal Items

Other personal equipment and items will be needed while making discharge measurements, or when working in and around rivers, creeks, and streams. Waders or boots should be worn while making wading measurements. Waders should be loose fitting, even when allowing for heavy winter clothing.

Ice chains, as shown in figure 75, should be strapped onto the soles of boots or waders for use on steep or icy stream banks, and on rocky or smooth and slippery streambeds.

A properly fitted personal-floatation device (PFD) must be worn when working near, in, or over water. This includes while wading streams, and working on a cableway, bridge, or water retention or control structure, on ice, or in a boat.



Figure 75. A, Ice chains for boots and waders and B, Sure Grip Ice Treads for boots and waders.

Accuracy of Current-Meter Discharge Measurements

The accuracy of a discharge measurement is dependent on many factors, including the equipment used, the location and characteristics of the measuring section, the number and spacing of verticals, the rate of change in stage, the measurement of depth and velocity, presence of ice and (or) debris in the measuring section, wind, experience of the hydrographer, carefulness (or carelessness) of the hydrographer, and various conditions that can occur during the process of making the measurement. The evaluation of the accuracy of a measurement has long been a qualitative assessment that takes some or all of these factors into account. A quantitative measure of the accuracy for some discharge measurements can also be made. The following two sections of this chapter describe these methods.

Qualitative Evaluation

Every discharge measurement should be evaluated for accuracy using the qualitative method. Historically, this has been the preferred method, and the hydrographer should make this evaluation immediately after making the measurement. The evaluation should be based on the hydrographer's opinion of the accuracy of the measurement—not on how well, or how poorly, the measurement plots on the stage-discharge relation. It is difficult to provide written guidelines for making a qualitative evaluation of accuracy. A good qualitative evaluation depends mostly on the experience and training of the hydrographer. Several of the factors that should be considered by the hydrographer are as follows:

Measuring section.—Consider factors such as the uniformity of depths, the smoothness of the streambed, the streambed material (that is, smooth sand; small, firm gravel; large rocks; soft muck; and so forth), the ability to accurately measure the depth, the approach conditions, presence of bridge piers, and other conditions that would affect measurement accuracy.

Velocity conditions.—Consider smoothness of velocity, uniformity of velocity, very slow velocity, very high velocity, turbulence, obstructions that may affect the vertical velocity distribution, use of one-point or two-point method, length of counting (40 or more seconds versus half-counts), and other factors that affect accuracy of velocity measurements.

Equipment.—Consider the type of current meter used (Price AA, Price pygmy, acoustic, or electromagnetic), the type of depth-sounding equipment, and the condition of the equipment.

Spacing of observation verticals.—Use about 25 to 30 verticals for a discharge measurement, spaced so that no more than 5 percent of the total discharge is contained in each subsection. Although this is frequently difficult to attain, except in unusual cases, no more than 10 percent of the total discharge should be in a subsection. Otherwise, the accuracy will be negatively affected.

Rapidly changing stage.—Although discussed in previous sections of this chapter, this condition should also be considered when assessing the accuracy of the measurement. Using the shortcut methods previously described will result in less accurate measurements of discharge.

Ice measurements.—Making discharge measurements under ice cover is usually more difficult, and sometimes less accurate, than making open-water discharge measurements. Presence of slush ice, layered ice, and anchor ice will have adverse effects on accurate measurement of depth and velocity. Velocity distribution will be affected if the water surface is in contact with the ice. Freezing of water in the meter cups and pivot chamber may affect performance of the equipment.

Wind.—Wind can affect the accuracy of a discharge measurement by obscuring the angle of the current, or by creating waves that make it difficult to sense the water surface prior to making depth soundings. Wind can also affect the vertical-velocity distribution, particularly near the surface, and can cause vertical and (or) horizontal movement of the current meter while making a boat measurement, introducing possible error in velocity measurements.

The qualitative method of assessing the accuracy of a discharge measurement requires that the hydrographer consider all of the above items and their cumulative effect on the measurement accuracy. The front page of the discharge measurement note sheet (see figure 2) has space for describing (1) the cross section, (2) the flow, (3) the weather, and (4) any other flow conditions that relate to the accuracy. These descriptions, along with the type of equipment, number of verticals, velocity measurement method, and other measurement conditions, should provide the basis for rating the measurement as excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent).

For instance, a measurement might be rated as excellent (2 percent) if (1) the cross section is smooth, firm, and uniform; (2) the velocity is smooth and evenly distributed; (3) the equipment is in good condition; (4) the two-point velocity measurement method was used; and (5) weather conditions are good (no wind or ice). On the other hand, if several of these factors make it difficult to accurately measure depth and (or) velocity, the measurement might be rated fair (8 percent), or even poor (more than 8 percent).

As stated previously, it is not possible to provide absolute guidelines for making the qualitative evaluation of accuracy. As a general rule, the accuracy of most discharge measurements will be about 5 percent, or qualitatively a “good” measurement. This is sometimes used as the base-line accuracy, with accuracy upgraded to “excellent” when measuring conditions are substantially better than average, and accuracy downgraded to “fair” or “poor” when conditions are substantially worse than average. The qualitative-accuracy evaluation is based on the hydrographer's judgment. For more detailed qualitative-evaluation information on discharge measurements using ADCPs, see Oberg and others (2005) and Mueller and Wagner (2009).

Quantitative Evaluation

A quantitative-accuracy evaluation can be made for some current-meter discharge measurements by using the procedure described by Sauer and Meyer (1992), Herschy (1994), and the International Organization for Standardization (1997). These procedures compute the uncertainty, or standard error, using a root-mean-square error analysis of individual component errors. The component errors include errors in the measurement of width, depth, and velocity, and in computation procedures. These procedures can be used to compute the standard error for most discharge measurements made with the vertical-axis, cup-type current meter. These procedures do not apply to measurements made with other types of current meters, or other methods of making discharge measurements. Likewise, they do not apply to discharge measurements where wind, ice, boundary effects, flow obstructions, improper equipment, incorrect measuring procedures, and hydrographer carelessness are factors in the measurement.

The details of the Sauer and Meyer (1992) method are described in USGS Open-File Report 92-144, and therefore are not included in this chapter. A computer program is available to compute the standard error for individual discharge measurements, and it is recommended that this quantitative evaluation be made for each discharge measurement for which it applies. Computations using this method show that the standard error of individual discharge measurements can range from about 2 percent for ideal conditions, to about 20 percent for very poor measuring conditions. Standard errors range from about 3 percent to 6 percent for measurements having generally normal measuring conditions. The standard errors computed by this method are in close agreement with qualitative evaluations.

ADCP Discharge-Measurement Accuracy

There are many sources of error in an ADCP discharge measurement. A complete measurement is composed of the ADCP-measured channel subsection, extrapolated top subsection, extrapolated bottom subsection, and edge-estimated subsections.

The largest and most substantial subsection is the ADCP-measured channel subsection. Most errors can be greatly reduced if factors, such as moving bed, water temperature, salinity, cross-section choice, instrument configuration, and boat speed, are carefully considered and accounted for, as described in previous sections of this chapter. Software is usually provided by the manufacturer that can be used to compute the ADCP instrument error for the measured subsection.

Errors for the extrapolated top, bottom, and edge subsections will vary, depending upon the extrapolation methods and relative proportion of the total discharge represented in these subsections. Again, these errors can be kept to a minimum through proper choice of cross section and careful measurement of variables, such as ADCP transducer depth and distances from each shore to the nearest ADCP section.

Studies by Morlock (1996) and Oberg and Mueller (2007) concluded that ADCP discharge measurements can be used successfully for streamflow data collection under a variety of field conditions. In Morlock (1996), 31 ADCP discharge measurements were compared to discharge ratings defined by conventional methods for the period over which the ADCP measurements were made. These comparisons showed that 25 ADCP measurements were within 5 percent of the conventional measurements. Six of the ADCP measurements differed by more than 5 percent, the maximum departure being 7.6 percent.

The study by Morlock (1996) stated that ADCP discharge measurement error was indicated by the standard deviations of the ADCP discharge measurements. The standard deviations ranged from about 1 to 7 percent of the measurement discharges. The estimated error of each ADCP discharge measurement also was computed from formulas derived by the manufacturer of ADCPs. The computations of estimated measurement error assume that ADCP instrument- and unmeasured-subsection extrapolation errors are the main source of measurement error. The standard deviations for most ADCP discharge measurements were higher than the estimated measurement errors, indicating that significant components of measurement error were not related to the instruments; errors of this nature include temporal variations of flow. It was concluded that measurement precision can be positively affected by selection of a measurement location with minimal flow variations, and negatively affected by instrument- and boat-operation factors.

Uncertainties in Discharge Measurements

All discharge measurements, no matter how carefully made, are subject to uncertainty. The measurement uncertainty can be thought of as a quantitative measure of the dispersion of the measured discharge about the true discharge. This uncertainty arises because each measurement is subject to errors of unknown magnitude. The total uncertainty in a discharge measurement may arise from several sources, including:

- uncertainty in the measurement of the cross-sectional area, which in turn arises from the following:
 - uncertainty in measurements of width; and
 - uncertainty in measurements of depth;
- uncertainty in the measurement of the water-velocity profile, which in turn arises from the following:
 - instrument uncertainty;
 - pulsation and turbulence in open-channel flow;
 - deviation from our assumptions about the vertical-velocity distribution; and
 - uncertainty due to oblique angles in the flow velocity;
- uncertainty due to deviation from assumptions used in the computation procedures; and
- other random or systematic errors.

These component uncertainties can be combined to estimate the total uncertainty of a single discharge measurement. Where feasible, values for these component uncertainties should be estimated independently for each site.

The uncertainty is often expressed as a standard deviation. If we assume that measurement errors are normally distributed, then this uncertainty can be used to construct confidence intervals for the measured discharge value. For example, the true discharge can be expected to be within one standard deviation of the measured value at the 68-percent confidence level. At the 95-percent confidence level, the true discharge can be expected to be within two standard deviations of a single measured value.

Quality Assurance and Quality Control

It should be the goal of each hydrographer to make discharge measurements of the highest quality and with as little error as possible. As explained in other sections of this chapter there are many actions that must be performed before, during, and after the actual measuring process. In the many implicit decisions that must be made during the course of a discharge measurement, the hydrographer, through training and experience, must develop a keen sense of what is correct and incorrect through hydrologic/engineering judgment, and strive to continually take the correct course of action in making a discharge measurement. This is commonly known as quality assurance and quality control, sometimes referred to as QA/QC. Some of the QA/QC functions are implicit; that is, they are generally understood, performed automatically, and are not specifically defined in the measurement notes and sometimes must be accomplished through hydrologic/engineering judgement. Careful regard for safety, good hydrologic/engineering judgment, and observance of proper procedure are implicit functions that cannot be overstressed in making a precise and accurate discharge measurement. On the other hand, some actions are explicit, such as performing regular spin tests of current meters, or making check measurements when the first measurement may be suspect. Following are some of the QA/QC actions that should be observed for making high-quality discharge measurements. These are not all inclusive, and each hydrographer should always include and document any other actions that relate to the quality of the measurement. Additional QA/QC requirements are given in the QA/QC plan for each USGS Water Science Center.

- *Care of current meters, current profilers, and sounding equipment.*—Previous sections of this chapter describe the proper care of current meters, current profilers, and sounding equipment. Current meters are especially susceptible to damage and misalignment while in use, as well as in transit, if they are not properly protected. The hydrographer should follow all established guidelines to ensure that the streamgaging equipment, especially the current meter and (or) profiler, are in good work-

ing condition. While making a discharge measurement, the current meter should be periodically observed and checked to be sure it is operating smoothly and has not become fouled by debris, ice, or other obstructions.

- *Spin tests of current meters.*—One of the requirements for maintaining and checking current meters is a periodic, timed spin test under controlled conditions. The procedure for making a timed spin test is described in a previous section of this chapter. In addition, before, during, and after a discharge measurement, check that the rotor is turning smoothly and does not come to an abrupt stop.
- *Carefulness, good judgment, and proper procedure.*—It is the hydrographer's responsibility to apply proper procedures with care and good judgment while making streamflow measurements. These implicit functions of QA/QC should be observed at all times.
- *Computing and plotting the measurement on site.*—Compute a discharge measurement as soon as possible after it is completed. Do this at the site before leaving. If the measurement does not plot within 5 percent (or other specified percentage) of the rating curve in use, or if it is not in line with the previous trend of measurements, try to find an explanation. For instance, there may be an obvious change of the control that would explain the deviation. All such explanations should be documented in the measurement notes. If a satisfactory explanation cannot be found, then make a check measurement.
- *Making check measurements.*—If possible, while making a check measurement, select a different cross section from the original section and use a different current meter. Make the check measurement as close in time and gage height to the original measurement as possible.
- *Checking discharge measurements.*—In general, hand-computed discharge measurements are not checked for mathematical errors. Nevertheless, check measurements that do not plot within an acceptable percentage of the rating curve, or within the previous trend of measurements. Likewise, check measurements that define a significant extrapolation of the low end or high end of a rating curve. Discharge measurements recorded in an electronic notebook, such as the Aquacalc, are automatically computed and do not require checking.
- *Documentation of QA/QC.*—Document in the measurement notes, if possible, all measures taken to ensure that discharge measurements are accurate and of high quality. Some QA/QC measures require specific documentation independent of the measurement notes. For example, current-meter spin tests have specific forms that document the spin-test results and all repairs to the meter.

Safety Requirements

Practicing personal and overall safety is of utmost importance when working near, in, and above water. It is not the purpose of this chapter to describe all of the safety requirements; however, each hydrographer should be familiar with, and should observe, those requirements. Other documents provide the details of specific safety requirements for making wading measurements, and for working on ice, bridges, cableways, and boats. For instance, each USGS Water Science Center flood plan addresses such things as one-person versus multiple-person field parties, use of an approved PFD, and traffic control while making discharge measurements from bridges, cableway safety, and boat safety. USGS WRD Memorandum No. 99.32 (1999) provides safety guidance as it is related to discharge measurements, sampling, and other related streamgaging activities. Each Water Science Center has a safety officer and a safety plan; both should be consulted for specific safety issues.

Portable Weir-Plate Measurements

Current-meter measurements made in shallow depths and low velocities are usually inaccurate, if not impossible, to obtain. Under these conditions, a portable weir plate is a useful device for measuring the discharge.

A 90-degree V-notch weir is suitable because of its favorable accuracy at low flows. A weir made of 10- to 16-gage galvanized sheet iron will produce a free-flowing nappe, having the effect of a sharp-crested weir, and will give satisfactory performance. The thickness of the plate should vary with the size of the weir. Refer to figure 76 for recommended proportions. Decreasing the plate thickness on larger weirs will help maintain portability. The notch is cut, without sharpening, leaving a flat, even edge. Framing, in the form of small-angle irons, is required for medium and large sizes. Canvas attached on the downstream or upstream side prevents leakage under or around the weir. Eyebolts, properly placed, will secure rods driven in earth channels to stabilize the plate.

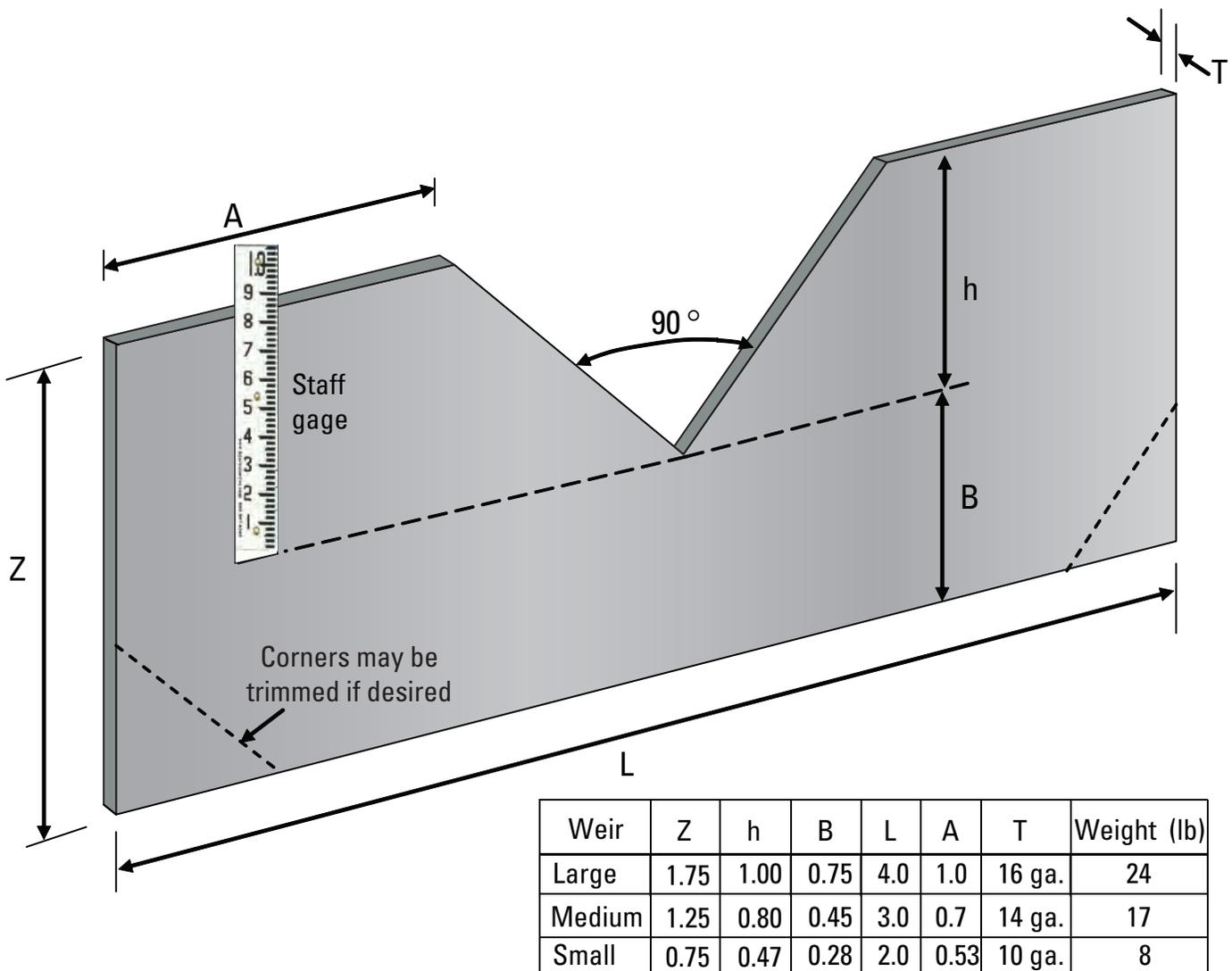


Figure 76. Portable weir plate.

Attach a staff gage to the upstream face of the weir plate, with the zero point at the same elevation as the bottom of the weir notch. The staff should be far enough from the notch to be outside of the zone of drawdown, which is a distance greater than twice the head on the notch. The staff gage is used to obtain head on the weir.

The general equation for flow over a sharp-edged triangular weir with a 90-degree notch is

$$Q = Ch^{\frac{5}{2}}, \tag{20}$$

where Q discharge, in ft³/sec,
 h static head, in ft, and
 C the coefficient of discharge.

The weir should be rated by determining the flow volumetrically for various values of head, or by having it rated in the HIF laboratory. In the absence of a rating, a value of C of 2.47 may be used.

Flows from 0.02 to 2.0 ft³/s are measured with the large weir of figure 76. Discharges can be measured within 3-percent accuracy if the weir is not submerged. A weir is not submerged when there is free circulation of air on all sides of the nappe.

To place the plate in a sand or silt channel, only a carpenter’s level and a shovel are needed. Push the weir into the streambed, and drive the rods through the eyebolts on each end to stabilize the weir. Use the level to make the top of the plate horizontal and the plate plumb. Another way to level the plate is by fastening a staff gage or level bubble to each end of the weir, where the staff gages are set at the same elevation. The plate is leveled by making the staff-gage readings identical or by using the level bubbles. Pack soil and streambed material around the ends and bottom of the weir to prevent leakage. Place canvas immediately downstream from the weir to prevent the falling jet from undercutting the streambed. Let the flow stabilize before making a measurement. Read the gage height at half-minute intervals for a period of about 3 minutes, and use a mean value in the above equation to compute the discharge. Ordinarily, one person can measure with a weir of this type. Remove the weir after you have completed the measurement.

Portable Parshall-Flume Measurements

A portable Parshall measuring flume is useful for measuring discharge when the depths are shallow and the velocities are low. The standard Parshall flume has a converging section, a throat, and a diverging section. The floor of the converging (or upstream) section is level both longitudinally and transversely when in place. The floor of the throat section slopes downward and the floor of the diverging or downstream section slopes upward. The standard Parshall flume can be used to measure discharge under free-flow conditions, as well as submerged conditions.

The flume used by the USGS is a modified version of the standard Parshall flume. The modification consists primarily of the removal of the downstream section, which reduces the weight of the flume and makes it easier to install. Because it has no downstream section, however, it can only be used to measure free-flow conditions (that is, where the submergence ratio is 0.6 or less). This can usually be accomplished by building up the streambed by a couple of inches under the level, converging floor of the flume when the flume is installed.

Free flow occurs when the ratio of the lower head to the upper head is less than 0.6. The discharge under this condition depends only on the length of crest (width of throat section) and depth of water at the upper gage. A flume that is properly constructed has an accuracy of 2 to 3 percent under free-flow conditions.

Install the flume by placing it in the channel; fill in with available channel bed or bank material around it to prevent any water from bypassing it. Use a carpenter’s level to set the floor of the converging section level. Some flumes are equipped with levels attached to the braces on the flume. After the flume is in place, the streamflow is allowed to stabilize before reading the gage. After the flow stabilizes, take gage readings at about half-minute intervals for about 3 minutes. Use an average of the gage readings with the flume rating to determine the discharge. Remove the flume after the measurement is complete.

A modified 3-in. Parshall flume is shown in figure 77. This modified version is virtually the same as the standard Parshall flume except that it does not have a diverging section. The gage height, or upstream head on the throat, is read in the small stilling well that is hydraulically connected to the flow by a 3/8-in. hole.

The basic rating equation for a flume is

$$Q = Cbh^{\frac{3}{2}}, \tag{21}$$

where Q discharge, in cubic feet per second (ft³/s),
 C a dimensionless coefficient of discharge that can vary with head and other factors,
 b width of the throat section, in feet, and
 h head, or gage height, in the converging section, in feet.



Figure 77. Modified 3-inch Parshall flume.

The rating for the 3-in. modified Parshall flume described in this section is given in table 12, and was taken from Buchanan and Somers (1969). An identical table is published by Kilpatrick and Schneider (1983), and also by Rantz (1982). The original source of this rating is unknown, but was probably based on laboratory tests. The rating in table 12 plots as a straight line on logarithmic plotting paper, and the equation for this rating was computed by regression analysis as follows:

$$Q = 1.1392h^{1.5797} \tag{22}$$

This equation is close to one that can be derived for the 3-in. modified Parshall flume, based on the procedures given by Kilpatrick and Schneider (1983). The above equation will reproduce values of discharge precisely as shown in table 12, except for a few instances where the computed discharge deviates by 0.001 to 0.005 ft³/s. This equation should not be used for values of gage height less than 0.01 ft or greater than 0.59 ft.

Table 12. Rating table for 3-inch modified Parshall flume.

[ft, feet; ft³/s, cubic foot per second]

Gage height (ft)	Discharge (ft ³ /s)	Gage height (ft)	Discharge (ft ³ /s)	Gage height (ft)	Discharge (ft ³ /s)
0.01	0.0008	0.21	0.097	0.41	0.280
0.02	0.0024	0.22	0.104	0.42	0.290
0.03	0.0045	0.23	0.111	0.43	0.301
0.04	0.0070	0.24	0.119	0.44	0.312
0.05	0.010	0.25	0.127	0.45	0.323
0.06	0.013	0.26	0.135	0.46	0.334
0.07	0.017	0.27	0.144	0.47	0.345
0.08	0.021	0.28	0.153	0.48	0.357
0.09	0.025	0.29	0.162	0.49	0.368
0.10	0.030	0.30	0.170	0.50	0.380
0.11	0.035	0.31	0.179	0.51	0.392
0.12	0.040	0.32	0.188	0.52	0.404
0.13	0.045	0.33	0.198	0.53	0.417
0.14	0.051	0.34	0.208	0.54	0.430
0.15	0.057	0.35	0.218	0.55	0.443
0.16	0.063	0.36	0.228	0.56	0.456
0.17	0.069	0.37	0.238	0.57	0.470
0.18	0.076	0.38	0.248	0.58	0.483
0.19	0.083	0.39	0.259	0.59	0.497
0.20	0.090	0.40	0.269		

Volumetric Measurements

The most accurate way of measuring small discharges is the volumetric method. This method is performed by observing the time it takes to fill a container of known capacity, or the time required to partly fill a calibrated container to a known volume. The basic equipment needed for this method is a calibrated container and a stopwatch.

Two methods can be used to calibrate the container. The first method is to add known volumes of water by increments and note the depth of water in the container. The second method is to first weigh the empty container and then add varying amounts of water to it, each time weighing the container with water, and noting the depth of water in the container. The following equation can then be used to compute the volume of water corresponding to the depth that was read:

$$V = \frac{W_2 - W_1}{w}, \quad (23)$$

where V volume of water in container, in cubic feet,
 W_2 weight of container with water, in pounds,
 W_1 weight of empty container, in pounds,
 w unit weight of water, 62.4 lb/ft³.

Volumetric measurements of discharge are made with two types of conditions:

- When the flow is or can be concentrated so that all of it may be diverted into a calibrated container.
- When the depth of water flowing over broad-crested weirs and dams is small and volumetric-increment samples can be obtained.

Under the first condition, measurements are made at V-notch weirs at artificial controls where all the flow is in a notch or catenary, and at places where a small earth dam can be built and all the water diverted through a pipe of small diameter. Sometimes it is necessary to place a trough against the artificial control to carry the water from the control to the calibrated container. If a small dam is built, the stage behind the dam must be allowed to stabilize before the measurement is begun. The measurement is made three or four times to ensure error-free and consistent results.

Volumetric measurements are made under the second condition by catching a segment of the streamflow with a container having a known width of opening. Samples are taken at a number of locations across the dam or weir similar to procedures used for current-meter measurements. The flow rate of each sample is increased by the ratio of the subsection width to the sampled width to obtain a discharge rate for each subsection. The total discharge of the stream is the summation of the discharge rates of each subsection.

Float Measurements

Floats have limited use in streamgaging, but they can be used where the velocity is too low to obtain reliable measurements with the current meter, or where flood measurements are needed and the measuring structure has been destroyed or it is impossible to use a meter. Both surface floats and rod floats can be used. Surface floats may be almost anything that floats, such as wooden disks, partly filled bottles, oranges, or pumpkins. Floating debris or ice cakes may serve as natural floats. Rod floats are usually made of wood and weighted on one end so they will float upright in the stream. Rod floats are sometimes made in sections so their length can be adjusted to fit the stream depth; however, they should not touch the streambed.

Two cross sections are selected along a reach of straight channel for a float measurement. The cross sections should be far enough apart so that the time the float takes to pass from one cross section to the other can be measured accurately. A travel time of at least 20 seconds is recommended, but a shorter time can be used on small streams with high velocities, where it is impossible to select an adequate length of straight channel. The edge of water for both cross sections should be referenced to stakes (or other marker) on each bank. Those points will be used at a later date, when conditions permit, to survey cross sections of the measurement reach, and to obtain the distance between cross sections. The surveyed cross sections will be used to determine the average cross section for the reach.

Float measurements may sometimes be made through a reach extending from the upstream to the downstream side of a bridge. This kind of reach may be useful where velocity is very slow and velocity observations by current meter are not reliable.

The procedure for a float measurement is to distribute a number of floats uniformly over the stream width, noting the position of each with respect to the bank. They should be placed far enough upstream from the first cross section so they attain the velocity of the stream before they reach the first cross section. Use a stopwatch to time their travel between the two cross sections. As each float passes the second cross section, note its distance.

The velocity of the float is equal to the distance between the cross sections divided by the time of travel. The mean velocity of flow in the vertical is equal to the float velocity multiplied by a coefficient that is based on the shape of the vertical-velocity profile and relative depth of immersion of the float. A coefficient of about 0.85 to 0.88 is commonly used to convert surface velocity to mean velocity. The coefficient for rod floats varies from 0.85 to 1.00, depending upon the shape of the cross section, the length of the rod, and the velocity distribution.

The procedure for computing discharge is similar to that for a mechanical current-meter measurement. The discharge in each partial section is computed by multiplying the average area of the partial section by the mean velocity in the vertical for that partial section. The total discharge is equal to the sum of the discharges for all the partial sections.

Discharge measurements made with floats under favorable conditions may be accurate to within ± 10 percent. Wind may adversely affect the accuracy of the computed discharge by its effect on the velocity of the floats, especially if velocity is very slow. If a poor reach is selected and not enough float runs are made, the results can be as much as 25 percent in error.

Indirect Discharge Measurements

During floods, it is frequently impossible or impractical to measure peak discharges when they occur. Roads may be impassable; structures from which current-meter measurements might have been made may be nonexistent, not suitably located, or destroyed; knowledge of the flood rise may not be available enough in advance to allow reaching the site near the time of the peak; the peak may be so sharp that a satisfactory current-meter measurement could not be made, even with a hydrographer present at the time; the flow of debris or ice can prevent use of a current meter; or personnel limitations might make it impossible to obtain direct measurements of high-stage discharge at numerous locations during a short flood period. Consequently, many peak discharges must be determined after the passage of the flood by indirect methods, such as slope-area, contracted-opening, flow-over-dam, or flow-through-culvert, rather than by direct current-meter measurement. Detailed descriptions of the procedures used in collecting field data and in computing the discharge are given by Benson and Dalrymple (1967), Dalrymple and Benson (1967), Bodhaine (1968), Matthai (1967), and Hulsing (1967), which are in book 3, chapters A1–A5, of the USGS Techniques and Methods series. Various computer programs are available for computing the discharge for indirect measurements.

Tracer Discharge Measurements

Measurement of discharge by this method depends on determination of the degree of dilution of an added tracer solution by the flowing water. A solution of a stable tracer, such as a fluorescent dye or a radioactive chemical, is injected into the stream at either a constant rate or all at once. The solution becomes diluted by the discharge of the stream. Measurement of the rate of injection, the concentration of the tracer in the injected solution, and the concentration of the tracer at a cross section downstream from the injection point permits the computation of stream discharge. The accuracy of the method critically depends upon complete mixing of the injected solution through the stream cross section before the sampling station is reached and upon no adsorption of the tracer on stream-bottom materials. The method is recommended only for those sites where conventional methods cannot be employed owing to shallow depths, extremely high velocities, or excessive turbulence. A detailed description of the procedures and equipment used in measuring discharge by a dye-dilution method is given by Kilpatrick and Cobb (1985).

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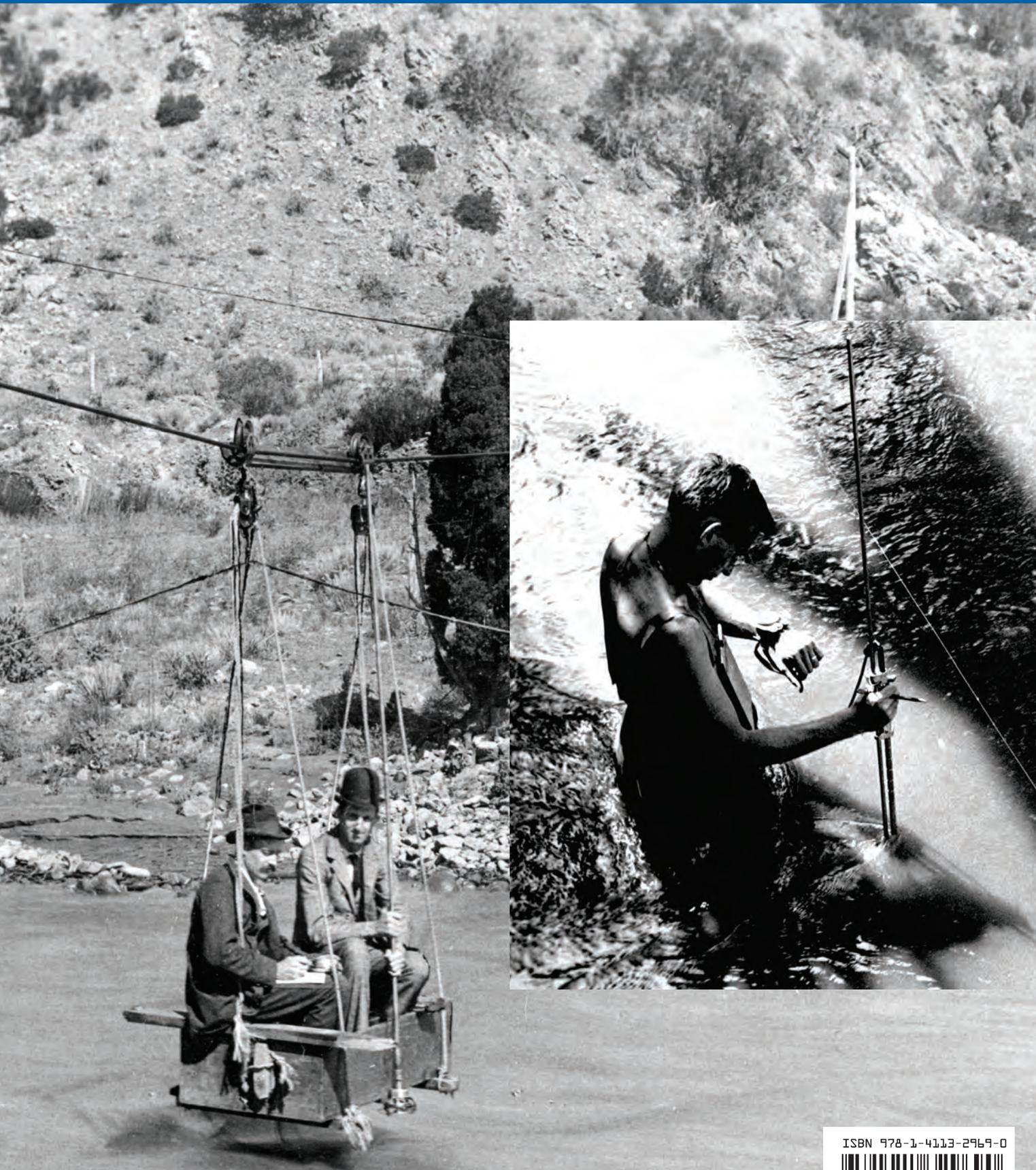


Exhibit B

HOBO TidbiT MX Temp 400 Manual

HOBO® TidbiT® MX Temp 400 (MX2203) and Temp 5000 (MX2204) Logger Manual



MX2203 Model Shown

HOBO TidbiT MX Temp Logger

Models:

- MX Temp 400 (MX2203)
- MX Temp 5000 (MX2204)

Items included:

- Protective boot

Required Items:

- HOBObconnect app
- Mobile device with Bluetooth and iOS, iPadOS®, or Android™, or a Windows computer with a native BLE adapter or supported BLE dongle

Accessories:

- Solar radiation shield (RS1 or M-RSA) for MX2203
- Mounting bracket for solar radiation shield (MX2200-RS-BRACKET), for use with MX2203 models
- Replacement O-rings (MX2203-ORING) for MX2203
- Replacement boots for both models in gray (BOOT-MX220x-GR), black (BOOT-MX220x-BK), or white (BOOT-MX220x-WH)

HOBO TidbiT MX Temp loggers measure temperature in streams, lakes, oceans, coastal habitats, and soil environments. Housed in a protective boot, these rugged loggers are designed for extended deployments in fresh or salt water at depths up to 400 ft (MX2203) or 5,000 ft (MX2204). The loggers use Bluetooth® Low Energy (BLE) for wireless communication with a phone, tablet, or computer, and are equipped with an optional water detection feature that automatically turns Bluetooth advertising off when the logger is submerged in water, preserving battery power. Using the HOBObconnect® app, you can easily configure the loggers, download logged data to your mobile device or computer, or automatically upload the data to HOBOLink® for further analysis. You can also configure the loggers to calculate statistics, set up alarms to trip at specific thresholds, or enable burst logging in which data is logged at a faster interval when sensor readings are above or below certain limits.

Specifications

Temperature Sensor

Range	MX2203: -20° to 70°C (-4° to 158°F) in air; -20° to 50°C (-4° to 122°F) in water MX2204: -20° to 70°C (-4° to 158°F) in air; -20° to 50°C (-4° to 122°F) in water, maximum sustained temperature in water 30°C (86°F)
Accuracy	±0.25°C from -20° to 0°C (±.45°F from -4° to 32°F) ±0.2°C from 0° to 70°C (±0.36°F from 32° to 158°F)
Resolution	0.01°C (0.018°F)
Drift	<0.1°C (0.18°F) per year
Response Time	MX2203: 17 minutes typical to 90% in air moving 1 m/s, unmounted; 7 minutes typical to 90% in stirred water, unmounted MX2204: 15 minutes typical to 90% in air moving 1 m/s, unmounted; 4 minutes typical to 90% in stirred water, unmounted

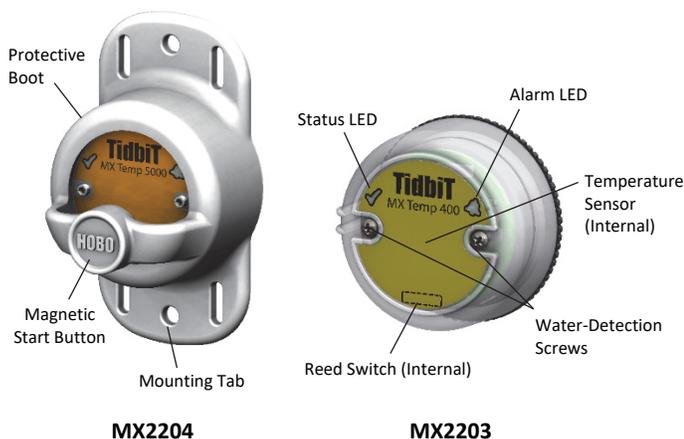
Logger

Logger Operating Range	-20° to 70°C (-4° to 158°F)
Buoyancy (Fresh Water)	MX2203: 3.1 g (0.11 oz) negative MX2204: 7.6 g (0.27 oz) negative
Waterproof	MX2203: To 122 m (400 ft) MX2204: To 1,524 m (5,000 ft)
Water Detection	Water conductivity level of 100 µS/cm or greater necessary for reliable detection of water. Deionized water or water below 100 µS/cm may not be detected. The water conductivity circuit may not reliably detect water that has frozen around the electrodes, i.e., below 0°C (32°F).
Radio Power	1 mW (0 dBm)
Transmission Range	Approximately 30.5 m (100 ft) line-of-sight
Wireless Data Standard	Bluetooth Low Energy (Bluetooth Smart)
Logging Rate	1 second to 18 hours
Time Accuracy	±1 minute per month at 25°C (77°F)
Battery	CR2477 3V lithium, user replaceable in MX2203, non-replaceable in MX2204
Battery Life	3 years, typical at 25°C (77°F) with logging interval of 1 minute and Bluetooth Always Off disabled in software. 5 years, typical at 25°C (77°F) with logging interval of 1 minute and Bluetooth Always Off or Bluetooth Off Water Detect enabled in the app. Faster logging intervals and statistics sampling intervals, burst logging, remaining connected with the app, excessive downloads, and paging may affect battery life. See <i>Battery Information</i> for detailed instructions on replacing the battery in the MX2203 logger.
Memory	96,000 measurements

Specifications (continued)

Full Memory Download Time	Approximately 45 seconds; may take longer the farther the device is from the logger.
Wetted Materials	MX2203: Polypropylene case, Delrin® battery cover, EPDM O-ring, stainless steel screws, Santoprene® (TPE) boot MX2204: Epoxy case, Santoprene (TPE) boot
Dimensions	MX2203: 4.45 x 7.32 x 3.58 cm (1.75 x 2.88 x 1.41 inches) MX2204: 4.06 x 6.99 x 3.51 cm (1.6 x 2.75 x 1.38 inches)
Weight	MX2203: 36.2 g (1.28 oz) MX2204: 32.8 g (1.16 oz)
Environmental Rating	IP68
	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).
	See last page

Logger Components and Operation



Protective Boot: This waterproof cover protects the logger during deployment. It has two mounting tabs and a built-in magnet to use with the logger's internal reed switch (see *Deploying and Mounting the Logger*).

Magnetic Start Button: This button is functional when the logger is inside the protective boot. Press this button for 3 seconds to start or stop the logger when it is configured to start or stop On Button Push (see *Configuring the Logger*). Press this button for 1 second to wake up the logger (if configured with Bluetooth Always Off as described in *Configuring the Logger*). You may need to press the button a second time to wake up the logger if it is logging every 5 seconds or faster and the temperature is -10°C (14°F) or below.

Mounting Tab: Use the tabs at the top and bottom of the logger to mount it (see *Deploying and Mounting the Logger*).

Reed Switch: The logger has an internal reed switch represented by the dotted rectangle on the logger. The reed switch is used in conjunction with the magnetic button in the protective boot. When the logger is removed from the boot, a magnet placed over the reed switch can substitute for the built-in button (see *Deploying and Mounting the Logger*).

Water Detection Screws: These two screws can detect the presence of water. This allows you to configure the logger in power-saving mode in which Bluetooth advertising is active only when the logger is removed from water. See *Configuring*

the Logger for details. **Note:** The logger checks for the presence of water every 15 seconds when the Bluetooth Off Water Detect power-saving mode is selected.

Temperature Sensor: The internal temperature sensor (not visible in the diagram) is located on upper right side of the logger.

Status LED: This LED blinks green every 4 seconds when the logger is logging (unless Show LED is disabled as described in *Configuring the Logger*). If the logger is waiting to start logging because it was configured to start On Button Push or with a delayed start, it blinks green every 8 seconds. Both this LED and the Alarm LED blink once when you press the button to wake up the logger or blink four times when you press the button to

start or stop logging. If you select  in the app, both LEDs are illuminated for 5 seconds (see *Getting Started* for more details).

Alarm LED: This LED blinks red every 4 seconds when an alarm is tripped (unless Show LED is disabled as described in *Configuring the Logger*).

Getting Started

Install the HOBObconnect app to connect to and work with the logger.

1. Download HOBObconnect to a phone or tablet from the App Store® or Google Play™.
Download the app to a Windows computer from www.onsetcomp.com/products/software/hobobconnect.
2. Open the app and enable Bluetooth in the device settings if prompted.
3. If this is the first time you are using the logger, firmly press the magnetic start HOBOb button near the center of the logger to wake it up. The alarm and status LEDs blink once when the logger wakes up. This also brings the logger to the top of the list if you are working with multiple loggers.
4. Tap Devices and then tap the logger tile in the app to connect to it.

If the logger does not appear in the list or if it is having trouble connecting, follow these tips.

- If the logger was configured with Bluetooth Always Off (see *Configuring the Logger*), it is currently logging at a fast interval (5 seconds or faster), and the temperature is -10°C (14°F) or below, you may need to press the button twice before it appears in the list.
- Make sure the logger is within range of your mobile device or computer. The range for successful wireless communication in air is approximately 30.5 m (100 ft) with full line-of-sight.
- Change the orientation of your device to ensure the antenna is pointed toward the logger. Obstacles between the antenna in the device and the logger may cause intermittent connections.
- If the logger is in water and configured with Bluetooth Off Water Detect, remove the logger from the water to connect to it.
- If your device can connect to the logger intermittently or loses its connection, move closer to the logger, within sight if possible. If the logger is in water, the connection can be unreliable. Remove it from water for a consistent connection.
- If the logger appears in the app, but you cannot connect to it, close the app and then power down your device to force the previous Bluetooth connection to close.

Once the logger is connected, you can:

Tap this:	To do this:
	Specify logger settings and save them onto the logger to start logging. See <i>Configuring the Logger</i> .
	Download (offload) logger data. See <i>Downloading Data From the Logger</i> .
	Start logging if the logger was configured to start with a button push. See <i>Configuring the Logger</i> .
	Stop logging data (this overrides any Stop Logging settings described in <i>Configuring the Logger</i>).
	Illuminate the logger LEDs for 5 seconds.
	Set a password for the logger that is required when another mobile device attempts to connect to it. To reset a password, press the button on the logger for 10 seconds or tap Manage Password and tap Reset.
	Mark the logger as a favorite. You can then filter the list of devices to show only loggers marked as favorites.



Update the firmware on the logger. A logger readout is completed automatically at the beginning of the firmware update process.

Important: Before updating the firmware on the logger, check the remaining battery level and make sure it is no less than 30%. Make sure you have the time to complete the entire update process, which requires that the logger remains connected to the device during the upgrade.

Configuring the Logger

Use the HOBObconnect app to set up the logger, including selecting the logging interval, start and stop logging options, and configuring alarms. These steps provide an overview of the set up features. For complete details, see the HOBObconnect User's Guide.

Note: Specify settings that are important to you. Press Start at any time to accept the defaults.

1. If the logger was previously configured with Bluetooth Always Off, press the button on the logger to wake it up. If the logger was previously configured with Bluetooth Off Water Detect and it is deployed in water, remove it from water. If you are working with multiple loggers, pressing the button also brings the logger to the top of the list in the app.
2. Tap Devices. Tap the logger tile in the app to connect to it.
3. Tap Configure & Start to configure the logger.
4. Tap Name and type a name for the logger (optional). If you do not enter a name, the app uses logger serial number as the name.
5. Tap Group to add the logger to a group (optional). Tap Save.
6. Tap Logging Interval and choose how frequently the logger records data unless operating in burst logging mode (see *Burst Logging*).
7. Tap Start Logging and select when logging begins:
 - **On Save.** Logging begins immediately after configuration settings are saved.
 - **On Next Interval.** Logging begins at the next even interval as determined by the selected logging interval.
 - **On Button Push.** Logging begins once you press the button on the logger for 3 seconds.
 - **On Date/Time.** Logging begins at a date and time you specify. Select the Date and time.
8. Tap Stop Logging and specify when logging ends.
 - **Never Stop (Overwrites Old Data).** The logger does not stop at any predetermined time. The logger continues recording data indefinitely, with newest data overwriting the oldest.
 - **On Date/Time.** The logger stops logging on a specific date and time that you specify.
 - **After.** Select this if you want to control how long the logger should continue logging once it starts. Choose the amount of time you want the logger to log data.

For example, select 30 days if you want the logger to log data for 30 days after logging begins.

- **Stop When Memory Fills.** The logger continues recording data until the memory is full.
9. Tap Pause Options, then select Pause On Button Push to specify that you can pause the logger by pressing its button for 3 seconds.
 10. Tap Logging Mode. Select either Fixed or Burst logging. With fixed logging, the logger records data for all enabled sensors and/or selected statistics at the logging interval selected (see *Statistics Logging* for details on choosing statistics options). In burst mode, logging occurs at a different interval when a specified condition is met. See *Burst Logging* for more information.
 11. Enable or disable Show LED. If Show LED is disabled, the alarm and status LEDs on the logger are not illuminated while logging (the alarm LED does not blink if an alarm trips). You can temporarily turn on LEDs when Show LED is disabled by pressing the button on the logger for 1 second.
 12. Select the power saving mode, which determines when the logger advertises or regularly sends out a Bluetooth signal for the phone, tablet, or computer to find via the app.
 - **Bluetooth Always Off.** The logger advertises only during logging when you press the button on the protective boot (or place a magnet where the reed switch is located if the logger is out of the protective boot). This wakes up the logger when you need to connect to it. This option uses the least battery power.
 - **Bluetooth Off Water Detect.** The logger does not advertise when the presence of water is detected. Once the logger is removed from the water, advertising automatically turns on, thereby not requiring you to push a button (or use a magnet) to wake up the logger when you need to connect to it. This option preserves some battery power. **Note:** The logger checks for the presence of water every 15 seconds when this is option is selected.
 - **Bluetooth Always On.** The logger always advertises. You never need to push a button (or use a magnet) to wake up the logger. This option uses the most battery power.
 13. Set up alarms to trip when a sensor reading rises above or falls below a specified value. See *Setting up Alarms* for details on enabling sensor alarms.
 14. Tap Start to save the configuration settings and start logging. Logging begins based on the settings you selected. See *Deploying and Mounting the Logger* for details on mounting and see *Reading Out the Logger* for details on downloading.

Setting up Alarms

You can set up alarms for the logger so that if a sensor reading rises above or falls below a specified value, the logger alarm LED blinks and an alarm icon appears in the app. Alarms alert you to problems so you can take corrective action.

To set an alarm:

1. Tap Devices. If the logger was configured with Bluetooth Always Off enabled, press the HOBOS button on the logger to wake it up. If the logger was configured with Bluetooth Off Water Detect and is currently underwater, remove it from the water.
2. Tap the logger tile to connect to it and tap Configure & Start.
3. Tap a sensor (tap the Enable Logging toggle if necessary).
4. Tap Alarms to open that area of the screen.
5. Select Low to have an alarm trip when the sensor reading falls below the low alarm value. Enter a value to set the low alarm.
6. Select High to have an alarm trip when the sensor reading rises above the high alarm value. Enter a value to set the high alarm.
7. For Duration, select how much time should elapse before the alarm trips and select one of the following:
 - **Cumulative.** The alarm trips once the sensor reading is out of the acceptable range for the selected duration any time during logging. For example, if the high alarm is set to 85°F and the duration is set to 30 minutes, then the alarm trips once the sensor readings have been above 85°F for a total of 30 minutes since the logger was configured.
 - **Consecutive.** The alarm trips once the sensor reading is out of the acceptable range continuously for the selected duration. For example, the high alarm is set to 85°F and the duration is set to 30 minutes; the alarm trips only if all sensor readings are 85°F or above for a continuous 30-minute period.
8. In the configuration settings, select one of the following options to determine how to clear the alarm indicators:
 - **Logger Reconfigured.** The alarm indication displays until the next time the logger is reconfigured.
 - **Sensor in Limits.** The alarm indication displays until the sensor reading returns to the normal range between any configured high and low alarm limits.

When an alarm trips, the logger alarm LED blinks every 4 seconds (unless Show LED is disabled), an alarm icon appears in the app, and an Alarm Tripped event is logged. The alarm state clears when the readings return to normal if you selected Sensor in Limits in step 8. Otherwise, the alarm state remains in place until the logger is reconfigured.

Notes:

- The logger checks alarm limits at every logging interval. For example, if the logging interval is set to 5 minutes, the logger checks the sensor readings against your configured high and low alarm setting every 5 minutes.
- The actual values for the high and low alarm limits are set to the closest value supported by the logger. For example, the closest value to 85°F that the logger can record is 84.990°F. In addition, alarms can trip or clear when the sensor reading is within resolution specifications.
- When you download data from the logger, alarm events can be displayed on the plot or in the data file. See *Logger Events*.

Burst Logging

Burst logging is a logging mode that allows you to set up more frequent logging when a specified condition is met. For example, a logger is recording data at a 5-minute logging interval and burst logging is configured to log every 30 seconds when the temperature rises above 85°F (the high limit) or falls below 32°F (the low limit). This means the logger records data every 5 minutes as long as the temperature remains between 85°F and 32°F. Once the temperature rises above 85°F, the logger switches to the faster logging rate and records data every 30 seconds until the temperature falls back to 85°F. At that time, logging then resumes every 5 minutes at the fixed logging interval. Similarly, if the temperature falls below 32°F, the logger switches to burst logging mode again and records data every 30 seconds. Once the temperature rises back to 32°F, the logger returns to fixed mode, logging every 5 minutes.

Note: Sensor alarms, statistics, and the Stop Logging option Never Stop (Overwrites Old Data) are not available in burst logging mode.

To set up burst logging:

1. Tap Devices. If the logger was configured with Bluetooth Always Off enabled, press the HOBOS button on the logger to wake it up. If the logger was configured with Bluetooth Off Water Detect and is currently underwater, remove it from the water.
2. Tap the logger tile to connect to it and tap Configure & Start.
3. Tap Logging Mode and then tap Burst Logging.
4. Select Low and/or High and type a value to set the low and/or high levels.
5. Set the burst logging interval, which must be faster than the logging interval. Keep in mind that the faster the burst logging rate, the greater the effect on battery life and the shorter the logging duration. Because measurements are taken at the burst logging interval throughout the deployment, the battery usage is similar to what it would be if you had selected this rate for the fixed logging interval.

Notes:

- The high and low burst limits are checked at the burst logging interval rate whether the logger is in fixed or burst condition. For example, if the logging interval is set to 1 hour and the burst logging interval is set to 10 minutes, the logger always checks for burst limits every 10 minutes.
- The actual values for the burst logging limits are set to the closest value supported by the logger. In addition, burst logging can begin or end when the sensor reading is within the specified resolution. This means the value that triggers burst logging may differ slightly than the value entered.
- Once the high or low condition clears, the logging interval time is calculated using the last recorded data point in burst logging mode, not the last data point recorded at the fixed logging rate. For example, the logger has a 10-minute logging interval and logged a data point at 9:05. Then, the high limit was surpassed and burst logging began at 9:06. Burst logging then continued until 9:12 when the sensor reading fell back below the high limit. Now back in fixed mode, the next logging

interval is 10 minutes from the last burst logging point, or 9:22 in this case. If burst logging had not occurred, the next data point would have been at 9:15.

- A New Interval event is created each time the logger enters or exits burst logging mode. See *Logger Events* for details on plotting and viewing the event. In addition, if the logger is stopped with a button push while in burst logging mode, then a New Interval event is automatically logged and the burst condition is cleared, even if the actual high or low condition has not cleared.

Statistics Logging

During fixed interval logging, the logger records data for the temperature sensor and/or selected statistics at the logging interval selected. Statistics are calculated at a sampling rate you specify with the results for the sampling period recorded at each logging interval. The following statistics can be logged:

- The maximum, or highest, sampled value
- The minimum, or lowest, sampled value
- An average of all sampled values
- The standard deviation from the average for all sampled values

For example, the logging interval is 5 minutes. The logging mode is set to fixed interval logging and all four statistics enabled, and with a statistics sampling interval of 30 seconds. Once logging begins, the logger measures and records the actual temperature values every 5 minutes. In addition, the logger takes a temperature sample every 30 seconds and temporarily stores them in memory. The logger then calculates the maximum, minimum, average, and standard deviation using the samples gathered over the previous 5-minute period and log the resulting values. When downloading data from the logger, this results in five data series: one temperature series (with data logged every 5 minutes) plus four maximum, minimum, average, and standard deviation series (with values calculated and logged every 5 minutes based on the 30-second sampling).

To log statistics:

1. Tap Devices. If the logger was configured with Bluetooth Always Off enabled, press the HOBOS button on the logger to wake it up. If the logger was configured with Bluetooth Off Water Detect and is currently underwater, remove it from the water.
2. Tap the logger tile in the app to connect to it and tap Configure & Start.
3. Tap Logging Mode and then select Fixed Logging Mode.
4. Tap to turn on Statistics.

Note: Fixed Logging Mode records sensor measurements taken at each logging interval. The selections you make in the Statistics section add measurements to the recorded data.

5. Select the statistics you want the logger to record at each logging interval: Maximum, Minimum, Average, and Standard Deviation (average is automatically enabled when selecting Standard Deviation). Statistics are logged for all enabled sensors. In addition, the more statistics you record, the shorter the logger duration and the more memory is required.

- Tap Statistics Sampling Interval and select the rate to use for calculating statistics. The rate must be less than, and a factor of, the logging interval. For example, if the logging interval is 1 minute and you select 5 seconds for the sampling rate, then the logger takes 12 sample readings between each logging interval (one sample every 5 seconds for a minute) and uses the 12 samples to record the resulting statistics at each 1-minute logging interval. Note that the faster the sampling rate, the greater the impact on battery life. Because measurements are being taken at the statistics sampling interval throughout the deployment, the battery usage is similar to what it would be if you had selected this rate for the normal logging interval.

Setting a Password

You can create an encrypted password for the logger that is required if another device attempts to connect to it. This is recommended to ensure that a deployed logger is not mistakenly stopped or purposely altered by others. This password uses a proprietary encryption algorithm that changes with every connection.

To set a password:

- Tap Devices. If the logger is configured with Bluetooth Always Off enabled, press the HOBOS button on the logger to wake it up. If the logger is configured with Bluetooth Off Water Detect and is currently underwater, remove it from the water.
- Tap Lock Logger.
- Type a password and then tap Set.

Only the device used to set the password can connect to the logger without requiring you to enter a password; you must use a password to connect to the logger with any other device. For example, if you set the password for the logger with your tablet and then try to connect to the logger later with your phone, you must enter the password on the phone but not with your tablet. Similarly, if others attempt to connect to the logger with different devices, they also must enter the password. To reset a password, press the button on the logger for 10 seconds or connect to the logger and tap Manage Password and Reset.

Downloading Data From the Logger

To download data from the logger:

- Tap Devices.
- If the logger is configured with Bluetooth Always On, continue to step 3.
If the logger is configured with Bluetooth Always Off, press the button on the logger for 1 second to wake it up.
If the logger is configured with Bluetooth Water Detect and it is deployed in water, remove it from the water.
- Tap the logger tile in the app to connect to it and tap Download Data. The logger downloads data to the phone, tablet, or computer.
- When the export file has successfully been created, tap Done to return to the previous page or tap Share to use your device's usual modes of sharing.

You can also upload data automatically to HOBOLink, Onset's web-based software, using the app or the MX gateway. For

details, see the HOBOLink User Guide and see the HOBOLink help for details on working with data in HOBOLink.

Logger Events

The logger records the following events to track logger operation and status. You can view events in exported files or plot events in the app.

To plot events, tap HOBOLink and select a file to open.

Tap  (if applicable) and then tap . Select the events you want to plot and tap OK.

Event Name	Definition
Host Connect	The logger was connected to a mobile device.
Started	The logger started logging.
Stopped	The logger stopped logging.
Alarm Tripped/Cleared	An alarm has occurred because the reading was outside the alarm limits or back within range. Note: Although the reading may return to a normal range, an alarm cleared event will not be logged if the logger was set up to maintain alarms until reconfigured.
Button Up/Down	The button on the logger was pressed to wake it up/bring it to the top of the loggers list in the app.
New Interval	The logger has switched to logging at the burst logging rate or back to the normal rate.
Water Detect	The logger has been placed in water or removed from water.
Power Warn	The battery level dropped below 2.3 V.
Safe Shutdown	The battery level dropped below a safe operating voltage and performed a safe shutdown.

Deploying and Mounting the Logger

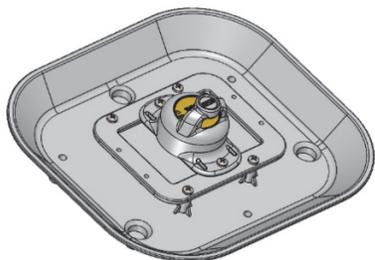
Follow these guidelines for deploying and mounting the logger.

- You can deploy the logger by using the two mounting tabs on the protective boot. Insert two screws through the holes on the mounting tabs to affix the logger to a flat surface. Insert cable ties through the rectangular holes on both mounting tabs to attach the logger to a pipe or pole.

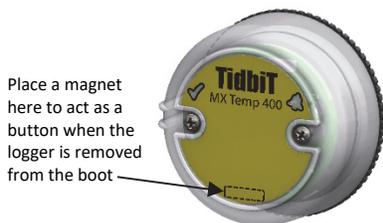


Use cable ties with the slots; slot dimensions are 0.28 cm (0.11 in.) wide x 0.86 cm (0.34 in.) long

- Use nylon cord or other strong cable with any of the holes on the mounting tabs. If wire is used to secure the logger, make sure the wire loop is snug to the holes. Any slack in the loop may cause excessive wear.
- When deploying in water, the logger should be appropriately weighted, secured, and protected depending on water conditions and desired measurement location.
- If the TidbiT MX Temp 500 (MX2203) logger will be exposed to sunlight in the deployment location, attach it to a solar radiation shield (RS1 or M-RSA) using the solar radiation shield bracket (MX2200-RS-BRACKET). Attach the logger to the underside of the mounting plate as shown. For more details on the solar radiation shield, refer to the *Solar Radiation Shield Installation Guide* at www.onsetcomp.com/manuals/rs1.



- Be careful of solvents. Check a materials compatibility chart against the wetted materials listed in the Specifications table before deploying the logger in locations where untested solvents are present. The TidbiT MX Temp 500 (MX2203) logger has an EPDM O-ring, which is sensitive to polar solvents (acetone, keton), and oils.
- The protective boot is designed with a magnetic button that will interact with the reed switch located inside the logger. This means you do not need to remove the boot to start, stop, or wake up the logger (if On Button Push or Bluetooth Always Off configuration settings have been selected). If you remove the logger from the boot or if the magnetic button in the boot is not working properly, you must place a magnet on the logger where the reed switch is located if you want to start or stop the logger with a button push or wake the logger up. Leave the magnet in place for 3 seconds to start or stop it or 1 second to wake it up.



Maintaining the Logger

- To clean the logger, remove the logger from the boot. Rinse both the logger and the boot in warm water. Use a mild dishwashing detergent if necessary. Do not use harsh chemicals, solvents, or abrasives.
- Periodically inspect the logger for biofouling if it is deployed in water and clean as described above.

- Periodically inspect the O-ring on the inside of the battery cover in the TidbiT MX Temp 400 (MX2203) logger for cracks or tears and replace it if any are detected (MX2203-ORING). See *Battery Information* for steps on replacing the O-ring.
- Periodically inspect the boot for any cracks or tears and replace it if necessary (BOOT-MX220x-XX).

Protecting the Logger

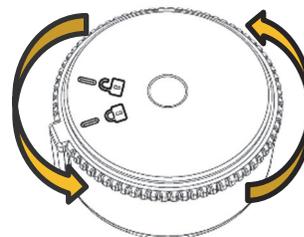
Note: Static electricity may cause the logger to stop logging. The logger has been tested to 8 KV, but avoid electrostatic discharge by grounding yourself to protect the logger. For more information, search for “static discharge” on www.onsetcomp.com.

Battery Information

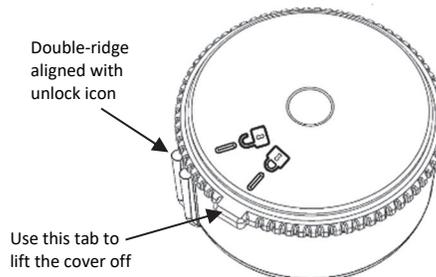
The logger requires one CR2477 3V lithium battery (HRB-2477), which is user-replaceable for the TidbiT MX Temp 400 (MX2203) and non-replaceable for the TidbiT MX Temp 5000 (MX2204). Battery life is 3 years, typical at 25°C (77°F) with a logging interval of 1 minute and Bluetooth Always On selected or 5 years, typical at 25°C (77°F) when the logger is configured with Bluetooth Always Off or Bluetooth Off Water Detect selected. Expected battery life varies based on the ambient temperature where the logger is deployed, the logging interval, the frequency of connections, downloads, and paging, and the use of burst mode or statistics logging. Deployments in extremely cold or hot temperatures or a logging interval faster than 1 minute can impact battery life. Estimates are not guaranteed due to uncertainties in initial battery conditions and operating environment.

To replace the battery in the TidbiT MX Temp 400 (MX2203) logger:

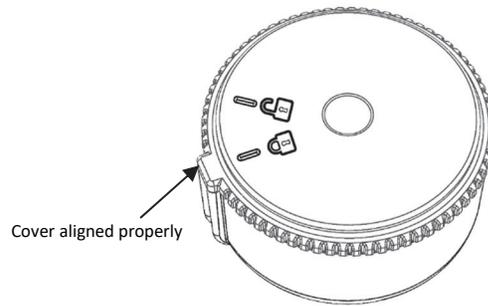
1. Remove the logger from the boot.
2. While pushing down on the back of the logger, rotate the cover counterclockwise. If your cover has lock icons, rotate it so that the icon moves from the locked to unlocked position. The unlocked icon will then line up with the double-ridge on the side of the logger case (pointed out in step 3).



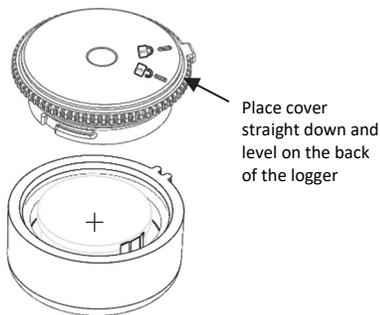
3. Use the small tab on the cover to lift it off the logger.



4. Remove the battery and place a new one in the battery holder, positive side facing up.
5. Inspect the O-ring on the battery cover. Make sure it is clean and seated properly. Remove any dirt, lint, hair, or debris from the O-ring. If the O-ring has any cracks or tears, replace it as follows:
 - a. Spread a small dot of silicone-based grease on the O-ring with your fingers, making sure the entire O-ring surface is completely covered in grease.
 - b. Place the O-ring on the cover and clean off any debris. Make sure the O-ring is fully seated and level in the groove and not pinched or twisted. This is necessary to maintain a waterproof seal.
6. Place the cover back on the logger, lining up the unlock icon (if applicable) with the double-ridge on the side of the logger case (shown in step 3). Make sure the cover is level as it is placed on the logger case to ensure the battery terminal maintains its proper position.



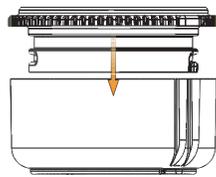
8. Place the logger back in the protective boot, making sure the double-ridge in the logger case slides into the groove on the inside of the boot.



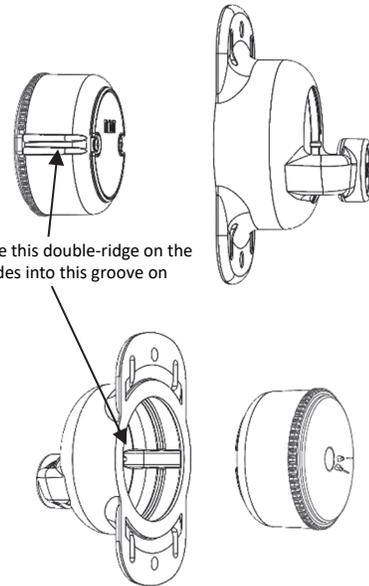
Battery Cover Placement Top View



Battery Cover Side View, Incorrect Assembly



Battery Cover Side View, Correct Assembly



Note: MX2203 logger is shown in the example; the groove in the boot on an MX2204 logger is in a slightly different location.

7. While pushing down on the cover, rotate it clockwise until the tab is aligned with the double-ridge in the logger case. If your cover has lock icons, then rotate it so that the icon moves from the unlocked to locked position. When the cover is properly positioned, the tab and the locked icon (if applicable) will be aligned with the double-ridge in the logger as shown.

⚠ WARNING: Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

Federal Communication Commission Interference Statement

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one of the following measures:

- Reorient or relocate the receiving antenna
- Increase the separation between the equipment and receiver
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
- Consult the dealer or an experienced radio/TV technician for help

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

FCC Caution: Any changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate this equipment.

Industry Canada Statements

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Avis de conformité pour l'Industrie Canada

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

To comply with FCC and Industry Canada RF radiation exposure limits for general population, the logger must be installed to provide a separation distance of at least 20cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

KC Statement

해당 무선설비는 전파혼신 가능성이 있으므로 인명안전과 관련된 서비스는 할 수 없음

Translation:

The service related to human safety is not allowed because this device may have the possibility of the radio interference.

Exhibit C

HOBO U20L Water Level Logger Manual



The HOBO U20L Water Level Logger is used for monitoring changing water levels in a wide range of applications, including streams, lakes, wetlands, tidal areas, and groundwater. Using HOBOware® Pro, you can easily configure this logger to record absolute pressure and temperature data. This logger features a ceramic pressure sensor, durable housing, and a protective end cap for deployment in existing wells or stilling wells. Without cumbersome vent tubes or desiccants to maintain, this easy-to-use logger is an ideal solution for water level studies and research.

Specifications

HOBO Water Level Logger

Models:

- U20L-01 (30-foot depth)
- U20L-02 (100-foot depth)
- U20L-04 (13-foot depth)

Required Items:

- Coupler (COUPLER2-C) with USB Optic Base Station (BASE-U-4) or HOBO Waterproof Shuttle (U-DTW-1, firmware version 3.2.0 or later)*
- HOBOware® Pro, version 3.5 or higher

Accessories:

- Cable (CABLE-1-300 or CABLE-1-50) and Cable Crimp (CABLE-1-CRIMP)
- Replacement Coupler (COUPLER2-C)

**If shuttle firmware version 3.2.0 or later is needed, see the Onset website or contact Onset Technical Support.*

Pressure (Absolute) and Water Level Measurements U20L-01

Operation Range	0 to 207 kPa (0 to 30 psia); approximately 0 to 9 m (0 to 30 ft) of water depth at sea level, or 0 to 12 m (0 to 40 ft) of water at 3,000 m (10,000 ft) of altitude
Factory Calibrated Range	69 to 207 kPa (10 to 30 psia), 0° to 40°C (32° to 104°F)
Burst Pressure	310 kPa (45 psia) or 18 m (60 ft) depth
Water Level Accuracy*	Typical error: ±0.1% FS, 1.0 cm (0.03 ft) water Maximum error: ±0.2% FS, 2.0 cm (0.06 ft) water
Raw Pressure Accuracy**	±0.3% FS, 0.62 kPa (0.09 psi) maximum error
Resolution	<0.02 kPa (0.003 psi), 0.21 cm (0.007 ft) water
Pressure Response Time (90%)*	<1 second at a stable temperature; measurement accuracy also depends on temperature response time

Pressure (Absolute) and Water Level Measurements U20L-02

Operation Range	0 to 400 kPa (0 to 58 psia); approximately 0 to 30.6 m (0 to 100 ft) of water depth at sea level, or 0 to 33.6 m (0 to 111 ft) of water at 3,000 m (10,000 ft) of altitude
Factory Calibrated Range	69 to 400 kPa (10 to 58 psia), 0° to 40°C (32° to 104°F)
Burst Pressure	500 kPa (72.5 psia) or 40.8 m (134 ft) depth
Water Level Accuracy*	Typical error: ±0.1% FS, 3.0 cm (0.1 ft) water Maximum error: ±0.2% FS, 6.0 cm (0.2 ft) water
Raw Pressure Accuracy**	±0.3% FS, 1.20 kPa (0.17 psi) maximum error
Resolution	<0.04 kPa (0.006 psi), 0.41 cm (0.013 ft) water
Pressure Response Time (90%)*	<1 second at a stable temperature; measurement accuracy also depends on temperature response time

Pressure (Absolute) and Water Level Measurements U20L-04

Operation Range	0 to 145 kPa (0 to 21 psia); approximately 0 to 4 m (0 to 13 ft) of water depth at sea level, or 0 to 7 m (0 to 23 ft) of water at 3,000 m (10,000 ft) of altitude
Factory Calibrated Range	69 to 145 kPa (10 to 21 psia), 0° to 40°C (32° to 104°F)
Burst Pressure	310 kPa (45 psia) or 18 m (60 ft) depth
Water Level Accuracy*	Typical error: ±0.1% FS, 0.4 cm (0.013 ft) water Maximum error: ±0.2% FS, 0.8 cm (0.026 ft) water
Raw Pressure Accuracy**	±0.3% FS, 0.43 kPa (0.063 psi) maximum error
Resolution	<0.014 kPa (0.002 psi), 0.14 cm (0.005 ft) water
Pressure Response Time (90%)*	<1 second at a stable temperature; measurement accuracy also depends on temperature response time

Specifications (continued)

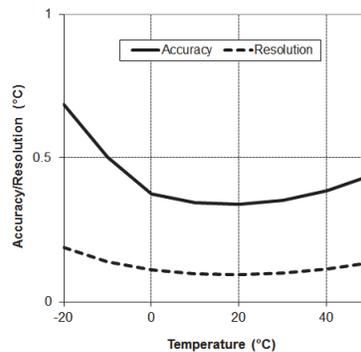
Temperature Measurements (All Models)

Operation Range	-20° to 50°C (-4° to 122°F)
Accuracy	±0.44°C from 0° to 50°C (±0.79°F from 32° to 122°F), see Plot A
Resolution	0.10°C at 25°C (0.18°F at 77°F), see Plot A
Response Time (90%)	10 minutes in water (typical)
Stability (Drift)	0.1°C (0.18°F) per year

Logger

Real-time Clock	±1 minute per month 0° to 50°C (32° to 122°F)
Battery	2/3 AA, 3.6 Volt lithium, factory-replaceable
Battery Life (Typical Use)	5 years with 1 minute or greater logging interval
Memory (Non-volatile)	64K bytes memory (approx. 21,700 pressure and temperature samples)
Weight	Approximately 154 g (5.43 oz) in air Approximately 53.9 g (1.9 oz) in fresh water
Dimensions	3.18 cm (1.25 inches) diameter, 15.24 cm (6.0 inches) length; mounting hole 6.3 mm (0.25 inches) diameter
Wetted Materials	Polypropylene housing and lanyard; Viton and Buna-N O-rings; ceramic sensor in acetal end cap; stainless steel screws suitable for saltwater
Logging Interval	Fixed-rate or multiple logging intervals, with up to 8 user- defined logging intervals and durations; logging intervals from 1 second to 18 hours. Refer to the <i>HOBOWare User's Guide</i> for details.
Launch Modes	Immediate start and delayed start
Offload Modes	Offload while logging; stop and offload
Battery Indication	Battery voltage can be viewed in status screen and optionally logged in datafile. Low battery indication in datafile.
Environmental Rating	IP68
	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).

- * Water Level Accuracy: With accurate reference water level measurement, known water density, accurate Barometric Compensation Assistant data, and a stable temperature environment.
- ** Raw Pressure Accuracy: Absolute pressure sensor accuracy includes all sensor drift, temperature, and hysteresis-induced errors.
- *** Changes in Temperature: Allow 20 minutes in water to achieve full temperature compensation of the pressure sensor. Maximum error due to rapid thermal changes is approximately 0.5%.

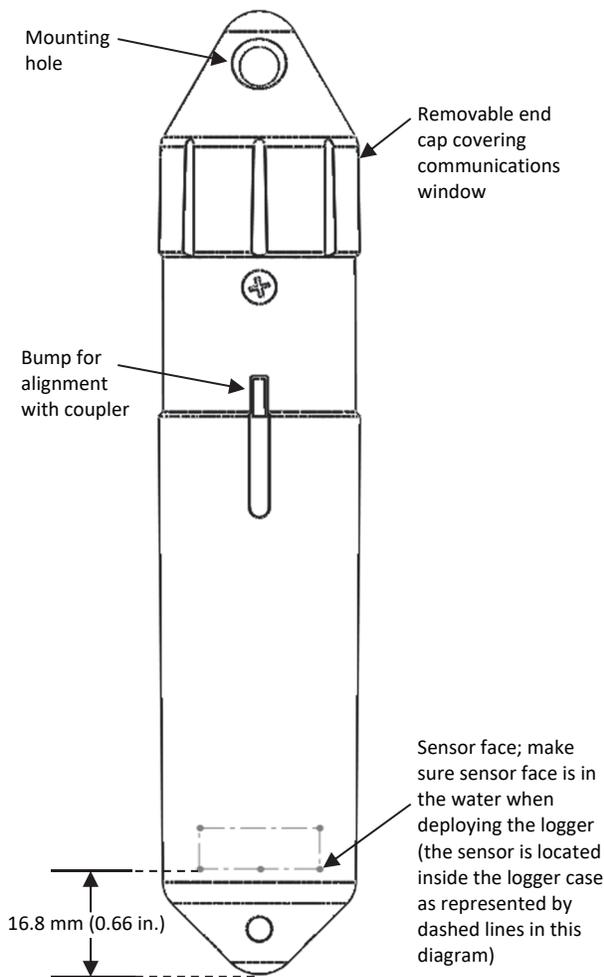


Plot A

Logger Operation

HOBOWare Pro software is required for logger operation. Using a reference water level, HOBOWare Pro automatically converts pressure readings into water level readings (see *Barometric Compensation* for more detail). The software also supports compensation for temperature, fluid density, and barometric pressure.

An LED in the communications window of the logger confirms logger operation. When the logger is logging, the LED blinks once every one to four seconds (the shorter the logging interval, the faster the LED blinks). The LED also blinks when the logger is recording a sample. When the logger is awaiting a start because it was configured to start “At Interval,” “On Date/Time,” or “Using Coupler,” the LED blinks once every eight seconds until logging begins.



The logger can record two types of data: samples and events. Samples are the sensor measurements recorded at each logging interval (for example, the pressure every minute). Events are independent occurrences triggered by a logger activity, such as Bad Battery or Host Connected. Events help you determine what was happening while the logger was logging.

Barometric Compensation

The logger records absolute pressure, which is later converted to water level readings by HOBOWare Pro software. In this application, absolute pressure includes atmospheric pressure and water head. Atmospheric pressure is nominally 100 kPa (14.5 psi) at sea level, but it changes with weather and altitude. Left uncompensated, barometric variations could result in errors of 0.6 m (2 ft) or more.

To compensate for barometric pressure changes, you can use another HOBO U20L Water Level logger as a barometric reference. The barometric reference is typically deployed in the same well or at the same location as the water level of interest, but rather than being placed in the water column, it is deployed above the water in air.

Barometric pressure readings are consistent across a region (except during fast-moving weather events), so you can generally use barometric pressure readings that are taken within 15 km (10 miles) of the logger or more without significantly degrading the accuracy of the compensation.

Therefore, one HOBO U20L or U20 Water Level logger or weather station (HOBO U30 recommended) can be used to compensate all the water level loggers in an area. The U20L-01 model with its 0–9m (0–30 ft) range or the U20L-04 with its 0–4 m (0–13 ft) range are both good barometric references due to their smaller range and temperature-compensated accuracy. HOBOWare Pro includes a Barometric Compensation Assistant for easy and accurate barometric compensation. See *Processing Water Level Data using Barometric Pressure Data* for more details.

Calibration

The pressure sensor in each HOBO U20L Water Level logger is individually calibrated. During calibration, raw pressure sensor data is collected at multiple pressures and temperatures over the calibrated range of the logger (see the specifications table). This data is used to generate calibration coefficients that are stored in the logger’s non-volatile memory. The calibration coefficients are then checked to be sure that the logger meets its stated accuracy over the calibrated range.

The pressure sensor can be used at pressures and temperatures that are outside of the calibrated range, but the accuracy cannot be guaranteed.

Important: Never exceed the burst pressure of the sensor!

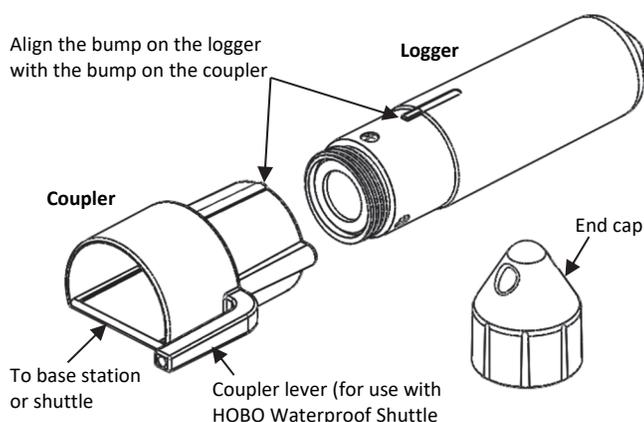
Connecting the Logger to a Computer

The HOBO Water Level Logger requires a coupler (COUPLER2-C) and Optic Base Station (BASE-U-4) or HOBO Waterproof Shuttle (U-DTW-1, firmware version 3.2.0 or later) to connect to the computer. The optical interface allows the logger to be offloaded without breaking the integrity of the seals. The USB compatibility allows for easy setup and fast downloads.

Important: USB communications may not function properly at temperatures below 0°C (32°F) or above 50°C (122°F).

1. Follow the instructions that came with your base station or shuttle to attach it to a USB port on the computer.
2. Unscrew the black plastic end cap from the logger by turning it counter-clockwise. **Note:** If the logger has been deployed, there may be water in the end cap. This is normal; this water will not penetrate the waterproof seal around the communications window in the logger.
3. Attach the coupler to the base station or shuttle.
4. Insert the logger into the coupler so that the alignment bump on the logger slides into the alignment bump on the coupler. Be sure it is properly seated in the coupler. It may take a few seconds for the new hardware to be detected by the computer.

NOTE: If you are using the Waterproof Shuttle, briefly press the coupler lever to put the shuttle into base station mode.



If the logger has never been connected to the computer before, it may take a few seconds for the new hardware to be detected by the computer.

WARNING: Do not leave the logger in the coupler for extended periods of time. When connected to a coupler, the logger is “awake” and consumes significantly more power than when it is disconnected and considered “asleep.” Always remove the logger from the Optic Base Station or HOBO Waterproof Shuttle as soon as possible after launching, reading out, or checking the status to avoid draining the battery. To “wake up” the logger, remove it from the coupler, wait a moment and then re-insert the logger.

Launching the Logger

Before deploying the HOBO U20 Water Level Logger in the field, perform the following steps in the office:

1. Open HOBOWare.
2. Connect the logger to the computer as described in the previous section.
3. From the Device menu, select Launch.
4. In the Launch Logger window, make sure both the Abs. Pressure and Temperature sensors are selected (temperature is required for temperature compensation of pressure).

5. Select any other launch settings as desired, including when to start logging and the logging interval. Click the Start button in the lower right corner of the Launch Logger window to send the launch settings to the logger (note that the Start button text changes based on the Start Logging selection).

Deploying the Logger

The HOBO Water Level Logger is designed to be easy to deploy in many environments. The logger uses an absolute pressure sensor, so no vent tube is required. The small size of the logger is convenient for use in small wells and allows the logger to be mounted and/or hidden in the field. Follow these guidelines when deploying the logger:

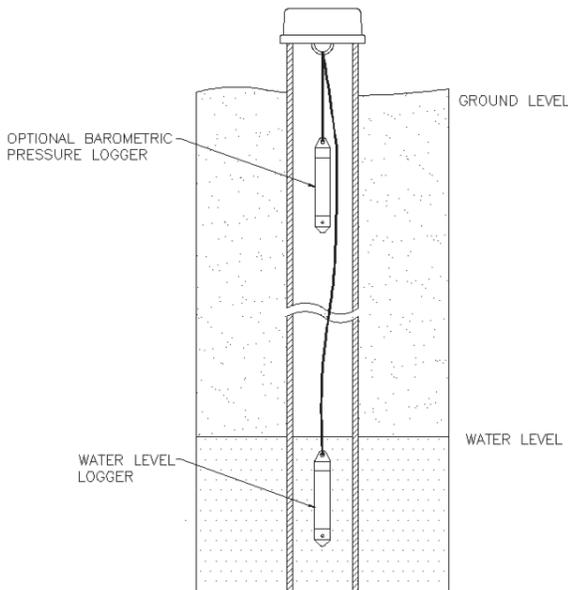
- The pressure sensor is temperature compensated over the range of 0° to 40°C (32° to 104°F). To obtain the highest level of accuracy, the logger should be allowed to come to full temperature equilibrium (approximately 20 minutes) before the reference level is recorded.
 - Sudden temperature changes should be avoided. When deploying a HOBO U20L Water Level Logger for barometric pressure reference, some consideration should be made to minimize the rate of temperature fluctuations. Ideally, the barometric pressure reference logger should be hung several feet below ground level in an observation well where ground temperatures are stable (while making sure the logger remains above the water level). If that is not possible (or if a well is not used), try to put the logger in a location where it will not be subject to rapid daily temperature cycles.
 - When deploying a HOBO Water Level logger in a well, make sure the well is vented to the atmosphere. Typically, a small hole can be drilled in the well cap to ensure that the pressure inside and outside the well is at equilibrium. If this is not possible, the barometric pressure reference logger should be used inside the same well.
 - Use a no-stretch wire to hang the water level logger. Any change in length of the wire will result in a 1-to-1 corresponding error in the depth measurement. Always pull-test a cable prior to deploying a logger in a well to make sure it does not stretch.
 - If you are deploying the logger in a lake, river, or stream, you must first build a stilling well to protect the logger from vibration, shock, and movement. A simple stilling well can be constructed with PVC or ABS pipe. A properly constructed stilling well helps to protect the logger from currents, wave action, and debris. Suspend the logger in the stilling well so it is always underwater, but not on the bottom to be buried by silt.
- For more information, see the Technical Application Note for Constructing a Stilling Well at:
http://www.onsetcomp.com/water_level_stilling_well.html
- To prevent the logger from moving in currents and to ensure the support cable is kept straight during deployment, you may need to add a weight to the suspension cable or hang a weight below the logger.

Alternatively, you could deploy the logger in a stilling well as described above.

- Be very careful not to exceed the burst pressure for the logger. The pressure sensor will burst if the maximum depth is exceeded (see specifications table). The logger should be positioned at a depth where the logger will remain in the water for the duration of the deployment, but not exceed the rated bursting depth.

To deploy the logger:

1. Cut wire to suspend logger.
 - a. Measure the physical depth to the surface of the water from the suspension point.
 - b. Cut a piece of stranded, stainless steel wire (Teflon coated is best) so that the logger will be deep enough to always be in the water. Estimate the low water level and make the cable length such that the logger will be about 2 feet below that level.
2. Attach the wire to the suspension point and to the logger cap.
3. Relaunch the logger if desired (if a laptop or a HOBO U-Shuttle is available).
4. Lower the logger into the well or stilling well.



5. Measure the water depth from the desired reference point (top of pipe, ground level, or sea level).
 - To maximize accuracy, allow 20 minutes after deploying the logger before measuring water depth to allow the logger to reach temperature equilibrium with the water.
 - If the well is too small in diameter to measure the water depth after deployment, measure the water depth before deployment, then deploy the logger immediately and record deployment time.
 - For well deployments: If the water level surface is below the reference point (such as referencing groundwater measurements to the top of the well), record the water level as a negative number. If the water level surface is

above the reference point (such as height above sea level), record the water level as a positive number.

- For lake, stream, and river deployments: If the water level is being referenced to some point above the logger (such as the top of the stilling well), record the water level as a negative number. If the water depth is being referenced to a point below the water surface such as the bottom of the stream, record the water level as a positive number.

6. Record the reference measurement date and time.

Deploying a Water Level Logger for Barometric Pressure Data (Optional)

If you are using a U20 or U20L logger to record barometric pressure data, install one logger in one of the wells as follows:

1. Cut wire for suspending the logger.
 - a. Measure the physical depth to the surface of the water from the suspension point.
 - b. Cut a piece of stranded, stainless steel wire (Teflon coated is best) so that the logger will hang about 2 feet below the ground surface but always above the water surface.
2. Attach the wire to the suspension point and to the logger cap.
3. Relaunch the logger if desired (if a laptop or a HOBO U-Shuttle is available).
4. Lower the logger into the well or stilling well. Make sure the logger does not go below the water surface. See the diagram in the previous section.
5. Record the deployment time.

Reading Out the Logger

To read out the logger for water level data (see later in this section for steps to read out a water level logger used for barometric pressure data):

1. Measure the water depth using the original reference point with the correct sign.
2. Record depth and date and time.
3. Pull the logger out of the well.
4. Remove the logger from its cap, leaving the suspension undisturbed. Check the communications window for any fouling and wipe it off if necessary. **Note:** There may be water in the end cap. This is normal; this water will not penetrate the waterproof seal around the communications window in the logger.
5. Read out the data using a laptop or shuttle.
6. Save the data in a test folder location.
7. Redeploy the logger (optional) as described later in this section.

To read out a U20L logger used for barometric pressure data:

1. Remove the logger from the well.
2. Read out the data using a laptop or shuttle.

3. Save the data in a test folder location.
4. Redeploy the logger (optional) as described below.

If you are redeploying the logger, you must first make sure that it is launched. If you used the HOBO Waterproof Shuttle to offload data, the shuttle automatically performs a synchronized relaunch of the logger so that data is logged on the same measurement intervals. If you wish to change the launch settings, you must launch the logger using HOBOWare Pro.

The existing suspension can be reused as long as the water level logger remained in the water and the barometric logger remained out of the water for the entire test interval. Take a new reference reading with the date and time as described in this section. Record this information in your field notebook to use later to calibrate the data, which will zero out any drift error.

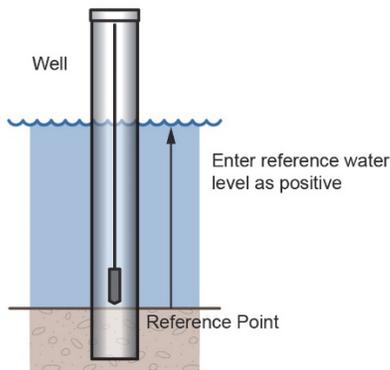
Processing Water Level Data using Barometric Pressure Data

To determine water level using barometric pressure data, use the Barometric Compensation Assistant in HOBOWare Pro as described below.

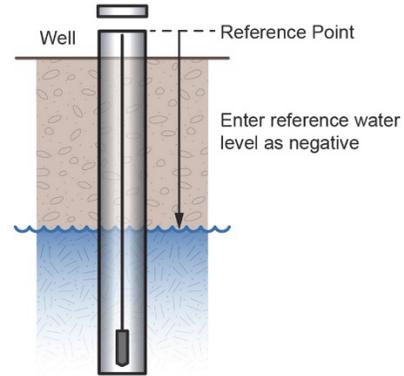
If you are using barometric pressure data from a HOBO weather station, you can use the data file as if it were U20L barometric data. For data from sources other than Onset products, see *Barometric Data from Other Sources* below.

1. In HOBOWare Pro, open the water depth data file. The Plot Setup window appears.
2. Uncheck all boxes except "Abs. Pressure."
3. Run the Barometric Compensation Assistant.
 - a. Select the assistant and click the Process button.
 - b. Select the water density box that best describes the water that you are measuring or enter the actual water density.
 - c. Check the Use a Reference Water Level box and enter the reference water level that you measured at the beginning of the deployment.

Enter the water level as a positive number if it is measured upward from a reference point below the water's surface, such as the water's height above sea level. This illustration shows an example of when to enter the water level as a positive number.



Enter the water level as a negative number if it is measured downward from a reference point above the water's surface, such as the top of the well. This illustration shows an example of when to enter the water level as a negative number.



- d. Select the date and time from the pull-down menu that is closest to the recorded date/time for the measurement. If you measured the depth before deployment because of pipe size, then select a date/time after the start of the deployment.
 - e. Check "Use Barometric Data file."
 - f. Click the Choose button. This will allow you to select the data file to use for barometric pressure compensation.
 - g. Select and open the data file.
 - h. Click the Create New Series button. A new Plot Setup window appears.
4. Select the Water Level checkbox and any other series that you want plotted. Click the Plot button to obtain a plot of the resulting water level data.

Measurement error can be caused by manual measurement error, sensor drift, or change in the suspension cable length.

To quantify measurement error (which is ideally zero), compare the calculated water level at the end of the plot with the water level measured just before you removed the water level logger.

Barometric Data from Other Sources

If you choose to use barometric pressure from a third-party weather station or barometric logger, you need to convert the date, time, and pressure data to a text file with special header requirements. For information on how to set up the text file, see the HOBOWare Help or User Guide. It is easiest to do this work in Microsoft® Excel® and then save it as a text file.

If you choose to use barometric pressure from an online weather station, such as the National Weather Service, the measured barometric pressure is modified to be at sea level. This sea level pressure is useable since all pressure offsets are zeroed when you enter the reference measurement.

When you select the barometric data file in the Barometric Pressure Assistant (see previous section), select the text file that you generated. Select tab or comma for the data format and data separation characters and then import the barometric data.

Maintenance

The logger requires the following periodic maintenance to ensure optimal operation:

- **Protect the logger. This logger can be damaged by shock.** Always handle the logger with care. The logger may lose its calibrated accuracy or be damaged if it is dropped. Use proper packaging when transporting or shipping the logger.

Important: Do not attempt to open the logger housing! Unscrewing the nose cone of the logger will cause serious damage to the pressure sensor and logger electronics. There are no user serviceable parts inside the case. Contact Onset Technical Support if your logger requires servicing.

- **Periodically inspect the logger for biofouling.** Biological growth on the face of the pressure sensor will throw off the pressure sensor's accuracy. Organisms that grow inside the sensor nose cone and on the sensor itself can interfere with the sensor's operation and eventually make the sensor unusable. If the deployment area is prone to biofouling, check the logger periodically for marine growth.
- **Be careful of solvents.** Check a materials-compatibility chart against the wetted materials listed in the Specifications table before deploying the logger in locations where untested solvents are present. The logger has Viton and Buna-N O-rings, which are sensitive to polar solvents (acetone, ketone), ammonia, chlorine, and brake fluids. The sensor is housed in an acetal end cap. Acetal is resistant to most solvents, fuels, and lubricants. The black polypropylene cap is provided to help protect the communications window. The polypropylene communications window is sealed as an additional barrier to prevent water and dirt from entering the logger housing.

Compensating for Drift

All pressure sensors drift over time. The drift for the pressure sensor and electronics in the HOBO U20L Water Level logger is less than 0.5% FS (worst case) per year. In most applications, drift is not a significant source of error, because the offset created by any drift is zeroed out when you take a manual reference level measurement and use the logger software to automatically calculate the level readings relative to the reference measurement. In effect, you are re-zeroing the sensor each time you apply a reference reading to the data file.

Pressure sensor drift matters only when absolute pressure values are needed, or if there are no recent reference level or depth measurements available. For example, if the logger is deployed for one year and no new reference level readings are taken during the deployment, it is possible that the sensor could have drifted as much as 0.5% FS by the end of the deployment.

It is possible to determine the actual amount of drift during a deployment if a reference level is taken at the beginning and the end of a long-term deployment. The results of applying the two different reference levels (once at the beginning of the data file, and again at the end of the data file) can be compared. Any difference between the files indicates the amount of sensor drift (assuming accurate reference levels).

Verifying Accuracy

You can check the *differential accuracy* of your loggers for water level measurements by deploying the loggers at two depths and comparing the difference in level readings. When verifying the accuracy this way, be sure to allow the loggers' temperature to stabilize at each depth. Use the logger software to convert the readings from pressure to level. The level readings should be taken close enough together that the barometric pressure does not change.

You can check the *absolute pressure accuracy* of your HOBO U20L Water Level Logger by comparing its ambient pressure readings to a second HOBO logger. Their readings should be within each other's specified accuracy. Alternatively, you can check the pressure reading against an accurate local barometer. If you use a non-local source of barometric information, such as the NOAA website, adjust for altitude.

Battery Guidelines

The battery in the HOBO U20L Water Level Logger is a 3.6 Volt lithium battery.

- **Battery Life.** The battery life of the logger should be about five years or more. Actual battery life is a function of the number of deployments, logging interval, and operation/storage temperature of the logger. Frequent deployments with logging intervals of less than one minute, and continuous storage/operation at temperatures above 35°C will result in significantly lower battery life. For example, continuous logging at a one-second logging interval will result in a battery life of approximately one month.

To obtain a five-year battery life, a logging interval of one minute or greater should be used and the logger should be operated and stored at temperatures between 0° and 25°C (32° and 77°F).

- **Battery Voltage.** The logger can report and log its battery voltage. If the battery falls below 3.1 V, the logger will record a "bad battery" event in the datafile. If the datafile contains "bad battery" events, or if logged battery voltage repeatedly falls below 3.3 V, the battery is failing and the logger should be returned to Onset for battery replacement.
- **Replace the Battery.** To have your logger's battery replaced, contact Onset or your place of purchase for return arrangements. Do not attempt to replace the battery yourself. Severe damage to the logger will result if the case is opened without special tools, and the warranty will be voided.

 **WARNING:** Do not cut open, incinerate, heat above 100°C (212°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

Exhibit D

HOBOconnect User Guide

HOBObconnect[®] User's Guide

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Getting Started

HOBObconnect is software designed to work with Bluetooth® Low Energy-enabled HOBOb® MX devices.

HOBObconnect:	Supports the following:
Mobile Device or Computer Requirements	Android™ 10.0 or later, iOS 13 or later, iPadOS® 13 or later, Windows® 10 or later, Bluetooth 4.0 or later. Note: The Windows app requires a native BLE adapter or supported BLE dongle. For details, see www.onsetcomp.com/products/software/hobobconnect .
Compatible HOBOb Devices	MX100, MX1101, MX1102A, MX1104, MX1105, MX2001, MX2200, MX2300, MX2501, MX Gateway

For specifications and detailed information about your MX device, refer to the product manual at www.onsetcomp.com/support/manuals.

Where to Download HOBObconnect

- Download the app from the App Store® or Google Play™ to your Android or Apple® phone or tablet. When installing the app, you must allow access to both the phone or tablet's location and to files on your device.
- Download the Windows app from www.onsetcomp.com/products/software/hobobconnect. When installing the app, you must grant permission for the app to access your computer's file system.

Introduction to the Main Icons

All the features within HOBObconnect are accessed through these three icons:

Tap this icon:	To do this:
	View and connect to loggers and gateways within range of your phone or tablet. Configure loggers, check status, view live data, read out logger data, set up gateways, and more.
	View logger readouts in a graph, export the files, and share them with others.
	Set up a dashboard to quickly see the latest measurements for in-range loggers.
	Change the app settings and access information about the app.

Usage Note: The examples in this guide are from the Android version of the HOBObconnect app. Screens in the iOS/iPadOS and Windows version of the app may vary slightly from the examples shown. In addition, if you are using a Windows computer and it does not have touchscreen capabilities, then use your mouse to click an icon instead of tapping as directed in this guide.

Viewing Devices

HOBOconnect uses Bluetooth Low Energy to communicate with all loggers and gateways within broadcast range of your phone, tablet, or computer (refer to the device manual for range specifications). Loggers that are awake and gateways will “advertise” or regularly send out a Bluetooth signal for the app to find. Tap Devices to view the devices within range. Information about each logger or gateway is shown in a tile, which can change color and may also have a bar on the left side depending on the logger state as detailed below.

The screenshot shows the 'Devices' screen in the HOBOnet app. At the top, there is a search bar and a filter icon. Below it, a list of devices is shown as tiles. The first tile is green (MX2201, Logging, 70.99 °F). The second tile is white (MX1101, Logging, 69.77 °F, 38.0 %). The third tile is gray (MX100, Awaiting Button Start, 68.75 °F). The fourth tile is white (MX Gateway, Gateway Running). A red bar is visible on the left side of the second tile. A bottom navigation bar contains icons for Devices, HOBOnet Files, Dashboard, and Settings.

Tap to filter the devices shown

Tap to change the device order

Bar color:	What it means:
Red	An alarm has tripped for the logger (also indicated by the alarm icon).
Orange	The device is in a recovery state, most likely because a firmware update was not completed.

Tile color:	What it means:
Green	A button was pressed on the logger to bring it to the top of the list (not available for all logger models).
White	Normal state: advertisements are being received regularly.
Gray	Stale state: no advertisements have been received recently.

Tap to view the list of Devices

Loggers with tripped alarms are listed first. If you've pressed a button on a logger to wake it up (not available on all logger models), then that logger will be at the top of the list. By default, all other loggers are listed in ascending order by name.

To change the order of the devices:

Tap  at the top right of the Devices screen, select one of the following, and tap Ok.

Select this:	To order devices by:
Name	Device name in ascending or alphabetical order. Serial numbers are used if the device was not configured with a name.
Group	Group name in alphabetical order. Devices not assigned to a group are listed after all devices in groups.
Serial #	Device serial number in ascending order. Even if the device was configured with a name, it will still be sorted by serial number.
Model	Device model number in ascending order (e.g., MX1101, MX2301, etc.).
Discovery time	When the app first received a Bluetooth advertisement from a device. The devices are ordered from the first discovered by the app to the last.

Note that the order selected can change slightly if a logger alarm trips or if no Bluetooth advertisements have been received.

To filter the devices shown:



Tap at the top left of the Devices screen, select All or one or more of the following, and tap Ok.

Select this:	To display the following devices within range:
All	All loggers and gateways.
Gateways	Only gateways.
Loggers	Only loggers.
Favorites	Loggers that have been marked as favorite (see <i>Logger Details and Actions</i> for details on favorites).
My Devices	Loggers and gateways that you have connected to with your phone or tablet. Note: You can clear this list by selecting Clear My Devices List in the app settings.
Ungrouped	All loggers that are not assigned to groups.
<Group Name>	Only loggers that have been configured with the selected group name (see <i>Configuring a Logger</i> for details on groups).

To search for a device:

Tap in the search field at the top of the Devices screen and enter one or more characters. You can search by serial number, logger or group name, or model number. The list will automatically be refined as each character is entered. Click X in the search field to cancel a search.

Checking Device Information

Loggers

Each tile includes the following information about the logger:

Name for the logger; the serial number is shown if no other name has been entered

An alarm has tripped (see *Viewing Devices* for more information on bar color)

Photo of logger model

Logger model number



Remaining battery power

Bluetooth signal strength

One or more alarms have tripped

Current logger status

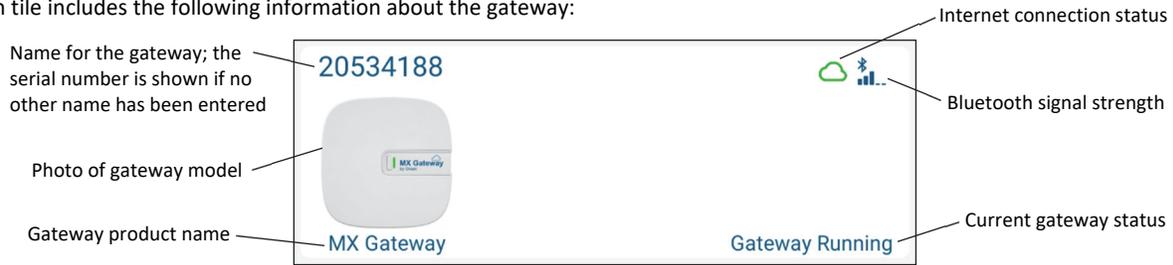
Current sensor readings (displayed even if the logger is not logging); on some models, these are updated at a different rate than the logging interval and may not match what is currently displayed on the logger LCD (if applicable).

Notes:

- **MX1104 and MX1105 loggers:** If the external sensor channel is disabled, the sensor reading is displayed as “- -”. Values from previously connected external sensors may display until the new sensors are configured and logging begins.
- **MX2001 loggers:** Sensor readings are displayed as “—” when the logger is stopped. Once logging begins, the readings shown are based on the reference water level and water density you entered.

Gateways

Each tile includes the following information about the gateway:



Using Bulk Download

The Bulk Download feature saves you time and allows you to download data easily and efficiently. You can download data from up to 20 loggers at a time, without having to connect to each logger.

On the Devices tab:

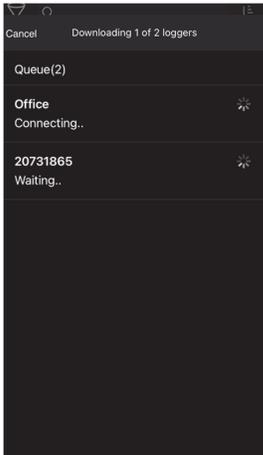
1. Click Bulk Download in the upper right corner of the screen.



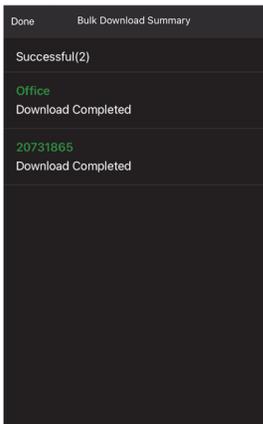
2. The screen changes to Bulk Download mode. This changes the way the screen behaves when you tap on a logger tile. Tap on a tile to select it for Bulk Download. You can select up to 20 loggers. Text at the bottom of the page updates to indicate how many loggers are selected.



- Click on Download X Loggers to begin the download. The downloads begin and run one after another. The screen displays the download queue.



- Click Cancel to cancel the downloads and return to the Devices screen, not in Bulk Download mode.
- The screen displays Done when all the loggers are downloaded.



Connecting to a Device

To connect to a device:

- Tap Devices.
- Find the logger or gateway to connect to by searching or scrolling through the tiles (wake up the logger first, if applicable).
- Tap the tile to connect to the logger or gateway. Enter your password if prompted. For MX2501 loggers, you may be prompted to calibrate the logger before configuring it.

Tips for connecting to a device:

- Make sure Bluetooth is enabled on the phone, tablet, or computer.
- MX100, MX1104, MX1105, MX2200, MX2300, or MX2501 loggers:** If the logger is in Bluetooth power saving mode, press the button on the logger to wake it up or remove the MX2203, MX2204, or MX2501 logger from the water if it is configured with Bluetooth Off Water Detect.
- A logger or gateway must be within range of the phone, tablet, or computer to connect to it (refer to the product manual for range specifications). Check the signal strength for the logger or gateway if you are having trouble connecting to it. If the signal strength shows only one or two blue bars, move the phone or tablet closer to the device.
- Check the batteries in the logger. Make sure the batteries are installed properly in new loggers and replace batteries in old loggers if battery voltage is low.

- Change the orientation of the phone, tablet, computer, or computer dongle to ensure the antenna is pointed toward the logger or gateway (refer to the device manual for the antenna location). Obstacles between the antenna in your device and the logger or gateway may result in intermittent connections.
- If the phone, tablet, or computer will not connect to a logger or gateway that appears in the list or if devices are not appearing in the list as expected, close the app and reopen it. If that still does not work, try closing the app and then powering down your device to force the Bluetooth connection to reset.
- **MX1102A loggers:** You cannot use HOBObconnect to connect to an MX1102A logger while a live USB session with HOBOWare® is underway. Disconnect the USB cable if you want to use the app to connect to the logger.
- **Gateways:** If the gateway is currently undergoing an automatic firmware update, then the phone, tablet, or computer will not be able to connect to it. The LED on the gateway will blink yellow during a firmware update and then resume normal operation after a few minutes.

Working with a Connected Logger

When the logger is connected to the phone, tablet, or computer, a screen like this example displays.

Tap this arrow to disconnect and return to the list of devices.

View the current logger status and sensor readings. On some models, current readings are updated at a different rate than the logging interval and may not match what is currently displayed on the logger LCD (if applicable).

View the current or most recent logger configuration settings.

Tap this icon to read out the logger (see *Reading out a Logger* for details).

Tap this icon to configure the logger (see *Configuring a Logger* for details).

On iPhones®, iPads®, or Android devices, tap to view more details about the logger and access logger password, stop logging, and other features (see *Logger Details and Actions*). **Note:** These features are all on the main screen in the Windows version.

Tap to view a graph of live data updated every 10 seconds. On iPhones, iPads, or Android devices, press and hold anywhere within the axes to view specific points. Note that these may differ from the logged data points; view the graph from a HOBOb file to see logged data.

Note for MX2001 loggers: When the logger is stopped, the water level reading shown does not reflect any reference water level and water density values you have entered (it reverts to a reference water level of zero and a water density of "Fresh Water adjusted for Temperature"). Once logging begins, the readings shown are then based on the reference water level and water density you entered.

Logger Details and Actions

When connected to a logger, you can view the following information about the logger (tap this icon  in the upper right corner first if applicable):

- Logger serial number, model number, and firmware version
- Percentage of memory used (if applicable, not available for all loggers)

- Remaining battery power
- Bluetooth signal strength

You can also access the following features described in this table.

Tap this icon:	To do this:
	Make the logger beep one time to help you locate it (MX1101, MX1102A, MX1104, and MX1105).
	Illuminate the logger LEDs for several seconds (MX100, MX2200, MX2300, and MX2501).
	Stop a beeping alarm when it trips on the logger (MX1101, MX1102A, MX1104, and MX1105). See <i>Configuring a Logger</i> for details on the Audible Alarm configuration setting.
	Update the firmware on the logger (only appears when new firmware is available). A logger readout will be completed automatically at the beginning of the firmware update process. If there is a communication failure during the firmware update process, some loggers may revert to the previous firmware. Note for MX2501 loggers: You will need to recalibrate the logger after updating the firmware.
<p>Important: Before updating the firmware on the logger, check the remaining battery level and make sure it is no less than 30%. Make sure you have the time to complete the entire update, which requires that your device remains within range of the logger during the update process. Do not switch to another app, turn off Bluetooth, or disturb the logger while the update is underway.</p>	
	Set a password for the logger so that it is not mistakenly stopped or reconfigured. Tap the icon, enter a password, and then tap Set. Once a password is entered on phone or tablet, that mobile device will be the only one to “remember” it. This means you can connect to the logger without entering a password on that mobile device, but you will be required to enter a password on all other mobile devices. For example, if you set the password for the logger with your tablet and then try to connect to the device later with your phone, you will be required to enter the password on the phone but not with your tablet. Similarly, if others attempt to connect to the logger with different devices, then they would also be required to enter the password. To reset a password: <ul style="list-style-type: none"> • Simultaneously press both the Start/Stop button and the Alarm/Stats button (MX1101), the Start/Stop button and the Next/Clear button (MX1102A), or the top and bottom buttons (MX1104 and MX1105) on the logger for 3 seconds; • Press the reset button between the batteries on the MX2001 logger; • Press the button on the MX100, MX2200, or MX2300 for 10 seconds; or • Tap this icon  and then tap Reset.
	Mark the logger as a favorite. You can then filter the list of devices to only show loggers marked as favorites. Tap this icon  to unmark the logger as a favorite.
	Start or resume logging. This is available if the logger was configured to start logging On Button Push or if the logger was configured to stop logging On Button Push and to Allow Button Restart (see <i>Configuring a Logger</i>).
	Stop logging.

Configuring a Logger

To configure a logger:

1. Tap Devices.
2. Find the logger by searching or scrolling through the tiles (wake up the logger first, if applicable).
3. Tap the tile to connect to the logger and then tap  towards the bottom of the screen. Read out the logger if prompted.
4. Make changes to the configuration settings by tapping a row (see the tables in this section for details on each setting).
5. Tap  to save the new configuration settings to the logger.

Notes:

- MX2501 loggers must be calibrated. You may be prompted to calibrate the logger automatically or you can tap . See *Calibrating an MX2501 pH and Temperature Logger* for details.
- You can update the water parameters for a MX2001 logger after it has been configured by tapping . See *Updating Water Parameters for an MX2001 Water Level Logger* for details.

Deployment Information

Deployment Information Setting	Description
Name	Type a name for the logger, which will also be used as the default data file name. If no name is entered, the logger serial number will be used as the name.
Group	Assign a logger to a group to help identify it. For example, if you have loggers deployed on three floors of a building, you can create a group for each of the three floors and then add each of the loggers to the appropriate group. Tap Group and then select an existing group or type a new group and tap Add. Tap Save. To delete a group: Tap Group, press and hold the group you want to delete, and tap  . To remove a logger from a group: tap Group, select None, and then tap Save.
Deployment Number	This is how many times the logger has been configured; it cannot be edited.
Deployment Date	This is the date and time the logger was last configured; it cannot be edited. If you need to change the time zone for your next deployment, change the settings on your phone or tablet.
Reference Water Level and Water Density	MX2001 loggers only: When the logger is stopped or you are configuring the logging, tap these two rows. If you tap Reference Water Level, enter the reference water level for the logger deployment, select the unit type, and tap Save. If you tap Water Density, select the water density, or enter your own value next to Manual Input and select the unit type, and then tap Save. You can also update these values during the deployment as needed (see <i>Updating Water Parameters for an MX2001 Water Level Logger</i>) or in the HOBOfile (see <i>Using the HOBOfile Viewer</i>).
pH Calibration	MX2501 loggers only: This shows the slope, offset, calibration points, and calibration time in place after calibrating the logger. See <i>Calibrating an MX2501 pH and Temperature Logger</i> for details.

Logger Setup

Logger Setup Setting	Description
Logging Interval	<p>Select the rate at which the logger will take measurements in hours, minutes, and seconds. Note that the faster the logging interval, the greater the impact on battery life and the shorter the logging duration. Note: If the logger is in burst logging mode, then measurements are taken at the burst logging interval (described later in this section).</p> <div style="border: 1px solid black; padding: 5px;"> <p>Important note for MX1102A loggers: Battery life for MX1102A loggers is less than 6 months when logging CO₂ and selecting a logging or sampling interval faster than 5 minutes. Select logging and sampling intervals of 5 minutes or slower when the carbon dioxide sensor is enabled to prolong battery life. If you select intervals faster than 5 minutes, you will need to replace the batteries more frequently.</p> </div> <p>MX1104, MX1105, MX2200, MX2300, and MX2501 loggers: If you configure an alarm, the logger will use the logging interval you selected as the rate to check for alarm conditions. If burst logging is configured, however, the logger will use the burst logging interval as the rate to check for burst trigger conditions instead of the logging interval.</p> <p>MX2001 loggers only: You can set a total of 8 logging intervals. Tap Logging Intervals, enter a rate in hours, minutes, and seconds for Interval 1. Tap Add to set up additional logging intervals. For each interval, enter the rate and select the number of samples that will be recorded for the selected rate. Tap Save. Note: You cannot change the number of samples if you are only using one logging interval. Tap  to delete a logging interval if needed.</p>
Logging Duration	<p>This is the approximate time it will take to fill the logger memory based on the logging interval and other factors, such as logging mode and sensors currently selected (if applicable). This is an estimate only and cannot be edited; battery life and other factors, such as the number of readouts performed, audible alarms (if applicable), and paging (if applicable) will also affect the deployment.</p>
Start Logging	<p>Tap Start Logging, choose one of the following and then tap Save:</p> <ul style="list-style-type: none"> • Now. Logging will begin immediately after saving the configuration settings. • On Next Logging Interval. Logging will begin at the next even interval as determined by the selected logging interval. This is useful if you want the logger to start and then subsequently log data on an even minute. • On Button Push. Logging will begin once you tap  in the app or you press the button on the logger (if applicable). • On Date/Time. Logging will begin on the date and time you specify. Select the date and time. Note that if you need to change the selected time zone, you must change your phone, tablet, or computer time zone settings and restart the app.
Stop Logging	<p>Tap Stop Logging, choose your options described below, and then tap Save. Note: Regardless of the options you select, you can stop the logger at any time by connecting to it, tapping  in the upper right corner (if applicable), and tapping .</p> <p>Memory Options</p> <ul style="list-style-type: none"> • When Memory Fills. The logger will continue recording data until the memory is full. • Never (Wrap When Full). The logger will continue recording data indefinitely, with newest data overwriting the oldest. This option is not available for loggers in which the logging mode is set to Burst. <p>Button Options</p> <ul style="list-style-type: none"> • Select On Button Push if you want to be able to stop logging by pressing the Start button on the logger for 3 or 4 seconds (not available for MX2001 loggers). • MX1101, MX1104, and MX1105 loggers: If you select the On Button Push setting for Stop Logging, then you also have the option to select Allow Button Restart. This

Logger Setup Setting	Description
Logging Mode	<p>allows you to pause and resume logging by pushing the Start/Stop button on the MX1101 logger or the top button on the MX1104 or MX1105 logger for 3 seconds.</p> <div style="border: 1px solid black; padding: 5px; margin: 10px 0;"> <p>Important: When Allow Button Restart is selected and you press the button, logging will restart on the next even logging interval. For example, a logger started logging at 7:00 AM with a logging interval set to 1 hour. If you press the button to stop the logger at 8:45 AM and then press the button again at 10:15 AM, logging will not begin immediately at 10:15 AM. Instead, logging will begin again at 11:00 AM, which is the next even interval time based on your 1-hour logging interval. Therefore, depending on the logging interval, the gap between the time you press the button to resume logging and the time actual logging begins could be significant. The faster the logging interval, the less time will elapse before logging resumes.</p> </div> <p>Time Options</p> <ul style="list-style-type: none"> • Never. Select this if you do not want the logger to stop at any predetermined time frame. • On Date/Time. Select this to set the date and time you want the logger to stop logging. Note that if you need to change the selected time zone, you must change your phone or tablet's time zone settings and restart the app. • After. Select this to set how long the logger should continue logging once it starts in days, hours, minutes, and/or seconds. For example, select 30 days if you want the logger to stop logging after for 30 days. <hr/> <p>Tap Logging Mode, select Fixed or Burst Logging Mode and choose any applicable setting, and tap Save (all models except MX100). MX2001 loggers only: You cannot change the logging mode if you have multiple logging intervals configured.</p> <p>Fixed Logging Mode</p> <p>The logger records data for enabled sensors and/or selected statistics at the logging interval selected. Any selected statistics are calculated at a sampling rate you specify with the results recorded at each logging interval.</p> <ol style="list-style-type: none"> 1. Select Normal to record the current reading for each enabled sensor at each logging interval. Do not select this if you <i>only</i> want to log statistics. MX2001 loggers only: You must select Normal if you want to log water level and barometric pressure data. If you deselect Normal, the logger will only record statistics series for the enabled sensors. It will not be able to calculate water level or barometric pressure. 2. Select the statistics you want the logger to record for all enabled sensors at each logging interval: <ul style="list-style-type: none"> • Maximum, the highest value from the sampling period • Minimum, the lowest value from the sampling period • Average, the mean of all values during the sampling period • Standard deviation from the average for all sampled values (requires average). 3. Set the Statistics Sampling Interval, which is the rate used for calculating statistics and must be a factor of the logging interval. For example, if the logging interval is 1 minute and you select 5 seconds for the sampling rate, then the logger will take 12 sample readings between each logging interval (one sample every 5 seconds for a minute) and use the 12 samples to record the resulting statistics at each 1-minute logging interval. Note that the more frequent the sampling rate, the greater the impact on battery life.

**Logger Setup
Setting**
Description

Important note for MX1102A loggers: Battery life for MX1102A loggers is less than 6 months when logging CO₂ and selecting a logging or sampling interval faster than 5 minutes. Select logging and sampling intervals of 5 minutes or slower when the carbon dioxide sensor is enabled to prolong battery life. If you select intervals faster than 5 minutes, you will need to replace the batteries more frequently.

Burst Logging Mode

The logger records data for enabled sensors at the normal logging interval until the readings rise above or fall below specific limits, at which time the logger switches to a faster burst logging rate until the readings return to normal. For example, the logger is configured with a logging interval of 5 minutes and burst logging is configured to log every 30 seconds when the temperature rises above 85°F (the high limit) or falls below 32°F (the low limit). This means the logger will record data every 5 minutes if the temperature remains between 32°F and 85°F. Once the temperature rises above 85°F, for example, the logger will switch to the faster logging rate and record data every 30 seconds until the temperature falls back to 85°F. At that time, logging then resumes every minute at the normal logging interval. Similarly, if the temperature falls below 32°F, for example, then the logger would switch to burst logging mode again and record data every 30 seconds. Once the temperature rises back to 32°F, the logger will then return to normal mode, logging every 5 minutes.

1. Select the burst logging interval, which must be faster than the logging interval.
2. Select Low and/or High for each sensor and either type or drag the slider to set the low and/or high values.

Notes:

- Sensor alarms, statistics, and the Stop Logging option Wrap When Full are not available in burst logging mode.
- The actual values for the high and low burst limits are set to the closest value supported by the logger.
- **MX1101, MX1102A, and MX2001 loggers:** Once the logger is configured, the high and low burst logging limits are only checked once every 15 seconds. Therefore, if you set the logging interval to less than 15 seconds and the sensor reading falls outside the limits, the burst logging will not begin until the next 15-second cycle.
- **MX1104, MX1105, MX2200, MX2300, and MX2501 loggers:** The high and low burst limits are checked at the burst logging interval rate whether the logger is in normal or burst mode. For example, if the logging interval is set to 1 hour and the burst logging interval is set to 10 minutes, the logger will always check for burst limits every 10 minutes.
- Once the high or low condition clears, the logging interval time will be calculated using the last recorded data point in burst logging mode, not the last data point recorded in normal mode. For example, a logger has a 10-minute logging interval and logged a data point at 9:05. Then, the high level was surpassed and burst logging began at 9:06. Burst logging then continued until 9:12 when the sensor reading fell back below the high level. Now back in normal mode, the next logging interval will be 10 minutes from the last burst logging point, or 9:22 in this case. If burst logging had not occurred, the next data point would have been at 9:15.
- If the logger is stopped with a button push while in burst logging mode, then a New Interval event is automatically logged and the burst condition is cleared, even if the actual high or low condition has not cleared. The logger will check the high and low conditions when logging resumes (if the logger was configured with Allow Button Restart selected; MX1101, MX1104, and MX1105 loggers only).

Logger Setup Setting	Description
Audible Alarm	<p>Tap the toggle to turn the audible alarm for the logger off or on (MX1101, MX1102A, MX1104, and MX1105 loggers only). If the audible alarm is on, then the logger will beep once every 30 seconds when an alarm trips until one of the following happens (whichever occurs first):</p> <ul style="list-style-type: none"> • The alarm is cleared from app (connect to the logger, tap  in the upper right corner (if applicable), and tap ). • One of the buttons on the logger is pressed. • Seven days have passed. <p>Notes:</p> <ul style="list-style-type: none"> • Once cleared, an audible alarm will start beeping again if the sensor values go out of the normal range. Even if an audible alarm is cleared, a visual alarm may remain on the logger LCD and in the app depending on the settings selected for maintaining visual alarms or because the alarm condition may still be in effect. In addition, an audible alarm will continue beeping when the sensor values have returned to the normal range until it is cleared. • It is recommended that you only enable this feature if you have regular access to the logger so that you can easily turn off the beeping. Note that battery life will be slightly reduced each time the audible alarm sounds.
Maintain Visual Alarms Until	<p>Select one of the following options and tap Save to determine how long the alarm icon will remain visible in the app (and illuminated on the logger LCD screen if applicable) after an alarm trips:</p> <ul style="list-style-type: none"> • Logger Reconfigured (all models except MX100 and MX2001). The alarm icon will remain visible until the next time the logger is reconfigured. • Sensor in Limits (all models except MX100). The alarm icon will remain visible until the sensor reading returns to the normal range between any configured high and low alarm limits. • Alarm Button Pressed (MX1101, MX1102A, MX1104, and MX1105 loggers). The alarm icon will remain visible until you press the Alarm/Stats button (MX1101), the Clear/Next button (MX1102A), or the bottom button (MX1104 and MX1105) on the logger. <p>Notes:</p> <ul style="list-style-type: none"> • MX100 loggers: The Maintain Visual Alarms Until setting is selected automatically when an alarm is configured. When an alarm trips, the logger alarm LED blinks every 4 seconds (unless Show LED is disabled), an alarm icon appears in the app, and an Alarm Out of Range event is logged. Even if the temperature reading returns to a normal range, the alarm indicator will not clear in the app and the alarm LED will continue to blink. • MX1101, MX1102A, MX1104, and MX1105 loggers: Although an audible alarm and a visual alarm can occur at the same time when a sensor alarm is tripped, they are cleared in different ways. The audible alarm can be cleared as described under the Audible Alarms section. Meanwhile, a visual alarm is cleared as determined by the three settings above. You may clear a beeping audible alarm, but the visual alarm remains on the LCD (if applicable) and in the app until the logger is reconfigured, the sensor is in limits, or the button is pressed (if applicable) -- whichever setting you selected. If the logger was configured to stop logging with a button push, any tripped alarms will be cleared automatically when logging is stopped and no Alarm Cleared event will be logged in the data file. This ensures that the logger will start checking for alarm conditions when logging resumes (if the logger was configured with Allow Button Restart selected; MX1101, MX1104, and MX1105 loggers only).

Logger Setup Setting	Description
Show LCD	Tap the toggle to control whether the LCD on the logger will remain illuminated during logging (MX1101, MX1102A, MX1104, and MX1105 loggers). When Show LCD is set to off, the LCD on the logger will not show the current reading, status, or other information during logging. You can temporarily turn the LCD screen on by pressing the button on the logger for 1 second. The LCD will then remain on for 10 minutes. In addition, you can view the status of any in-range logger on your phone or tablet regardless of the logger's LCD setting.
Show LED	Tap the toggle to control whether the LEDs on the logger are visible during logging (MX100, MX2200, MX2300, and MX2501 models). When Show LED is set to off, the alarm and status LEDs on the logger will not be illuminated during logging (the alarm LED will not blink if an alarm trips). You can temporarily turn on LEDs by pressing the button on the logger for 1 second.
Bluetooth Always On	Tap the toggle to control whether the logger will "advertise" or regularly send out a Bluetooth signal for the app to receive (MX100, MX1104, MX1105, MX2201, MX2202, and MX2300 loggers). When Bluetooth Always On is set to off, the logger will only advertise when you press the button on the logger to wake it up, thereby preserving as much logger battery power as possible. Note: If you are using an MX Gateway, Bluetooth is automatically enabled to ensure regular gateway uploads can occur.
Power Saving Mode	Select one of the following options and tap Save (MX2203, MX2204, and MX2501 models): <ul style="list-style-type: none"> • Bluetooth Always Off. The logger will only "advertise" or regularly send out a Bluetooth signal for the app to receive when you press the HOBOnnect button on the protective logger boot (MX2203 and MX2204) or press the switch (MX2501) to wake it up. This option uses the least logger battery power. • Bluetooth Off Water Detect. The logger will not advertise when the presence of water is detected. Once the logger is removed from the water, Bluetooth advertising will automatically resume. This option preserves some battery power. Note: The logger will check for the presence of water every 15 seconds when this option is selected. • Bluetooth Always On. The logger will always advertise. This option uses the most battery power.
Soil Type	Select one of the following options and tap Save: <ul style="list-style-type: none"> • Mineral. For common soils, with EC values up to 8 dS/m. • Soilless. For potting soils, perlite, and peat moss with EC values up to 8 dS/m. • Apparent Dielectric Permittivity. Raw measurements that can be used in published equations such as the Topp equation to derive soil moisture data.
Enable Percent of Field Capacity	Select Enable to see soil moisture as the percent of field capacity. Enter the Field Capacity for the soil at the site in Volumetric Water Content on a scale of 0.01 to 1.00. Note that the Percent of Field Capacity values reported will be limited to the range of 0% to 200%. If you selected Apparent Dielectric Permittivity as your soil type, the option for Percent of Field Capacity is disabled.
Upload Data via	Select how data from the logger is offloaded (If you upload data using HOBOnnect, you do not need a HOBOnlink account.) <ul style="list-style-type: none"> • Gateway. The gateway automatically uploads data from the logger to HOBOnlink on a regular basis (see <i>Configuring a Gateway</i> for details on setting up a gateway). Note: MX100 series loggers are not supported by the gateway. Contact Onset Technical Support for questions on MX100 logger compatibility with the gateway. • HOBOnnect. Offload data with any device running the HOBOnnect app. The data is stored on the device. You can configure HOBOnnect to automatically upload the data to HOBOnlink every time you read out the logger with the app see (<i>HOBOnnect Settings</i>) or you can share the data using email or messaging apps. Note: If "Upload Data via" is grayed out, then the Upload Data setting in the app has been disabled. See <i>HOBOnnect Settings</i> for details.

Sensors and Alarm Setup

Sensors & Alarm Setup Setting

Description

Follow these steps for general sensor and alarm setup. See the sections on MX1102A and MX1104/MX1105 sensor setup for additional instructions for those models.

1. Tap a sensor or channel. Tap the toggle to Enable Logging (if necessary).
2. Enter a name for the sensor or channel.
3. If you want to set an alarm for the sensor, select Low and/or High for each sensor and either type or drag the slider to set the low and/or high values.
4. Under Duration, select how many hours and/or minutes you want to elapse before the alarm is tripped and select one of the following:
 - Cumulative. The alarm will trip once the sensor reading is out of the acceptable range for the selected duration any time during logging. For example, if the high alarm is set to 85°F and the duration is set to 30 minutes, then the alarm will trip once the sensor readings have been above 85°F for a total of 30 minutes since the logger was configured.
 - Consecutive. The alarm will trip once the sensor reading is out of the acceptable range continuously for the selected duration. For example, the high alarm is set to 85°F and the duration is set to 30 minutes, then the alarm will only trip if all sensor readings are 85°F or above for a continuous 30-minute period.
5. Tap Save. Repeat the steps for another sensor if applicable.

Notes:

- If Temperature and RH measurements are being logged, then a dew point series will also be calculated and available in the data file upon readout or when viewing live data.
- **MX2001:** Differential pressure must be enabled to calculate water level. Temperature must be enabled to log absolute pressure. Temperature must also be enabled if you selected the water density option "Fresh Water adjusted for Temp."
- The actual values for the high and low alarm limits are set to the closest value supported by the logger.
- For MX1101 and MX2001 loggers and for MX1102A loggers powered by USB, alarm limits are checked every 15 seconds. For MX1102A loggers powered by batteries, CO₂ alarm limits are checked every 5 minutes (temperature and RH alarm limits are still checked every 15 seconds). If you are configuring a CO₂ sensor alarm for a battery-powered logger, it is recommended that the duration you select is divisible by 5 and a minimum of 5 minutes.
- For MX1104, MX1105, MX2200, MX2300, and MX2501 loggers, alarm limits are checked at each logging interval. If burst logging is configured, however, the logger will use the burst logging interval as the rate to check for burst trigger conditions instead of the logging interval.
- The alarm icon will be illuminated on the logger LCD (if applicable) when the alarm trips. You can also press the Alarms/Stats button (MX1101), Clear/Next button (MX1102A), or the bottom button (MX1104 and MX1105) on the logger to view the value that triggered the alarm. The LCD (if applicable) displays the farthest out-of-range sample during the deployment.

MX1102A Sensor Setup

When configuring the CO₂ sensor for the MX1102A logger, these settings are also available:

- **Altitude Compensation.** If the logger will be deployed at a location above or below 305 meters (1,000 feet), select Enable Altitude Compensation. Enter the altitude above sea level in meters or feet. **Note:** In normal use, the CO₂ measurement will vary by approximately 0.135% of the reading for each mbar change in barometric pressure (the

Sensors & Alarm Setup Setting

Description

sensor is calibrated at 1,013 mbar). Use altitude compensation when deploying the logger for the best CO₂ accuracy possible.

- **Manual Calibration.** Manual calibration is the best way to calibrate your logger. Use this option if you want to manually calibrate the logger to 400 ppm using the Calibrate button on the logger. This requires taking the logger outside in fresh air on a dry day or to an indoor location that is unoccupied and has no connection to a ventilation system for five minutes on a regular basis. This is recommended if the logger is deployed in a building that is always occupied, if you want the logger to be calibrated more frequently than every eight days (the normal auto calibration schedule), or if you want to calibrate the logger immediately after logging begins. **Note:** Every time the logger is started, auto calibration will occur after 24 hours and then again after eight days unless a manual calibration is performed first.
- **Auto Calibration.** Tap Automatic if you want the logger to automatically calibrate within the first 24 hours after logging begins and then every eight days thereafter. The logger will be calibrated based on the average of the three CO₂ measurements that follow the lowest CO₂ value identified during the 24-hour or 8-day time period as applicable.

Important: Accurate auto calibration requires the building or location where the logger is deployed to be empty at least once during the eight-day period (for example, an empty office building during the weekend or overnight will typically have background CO₂ levels of 400 to 450 ppm).

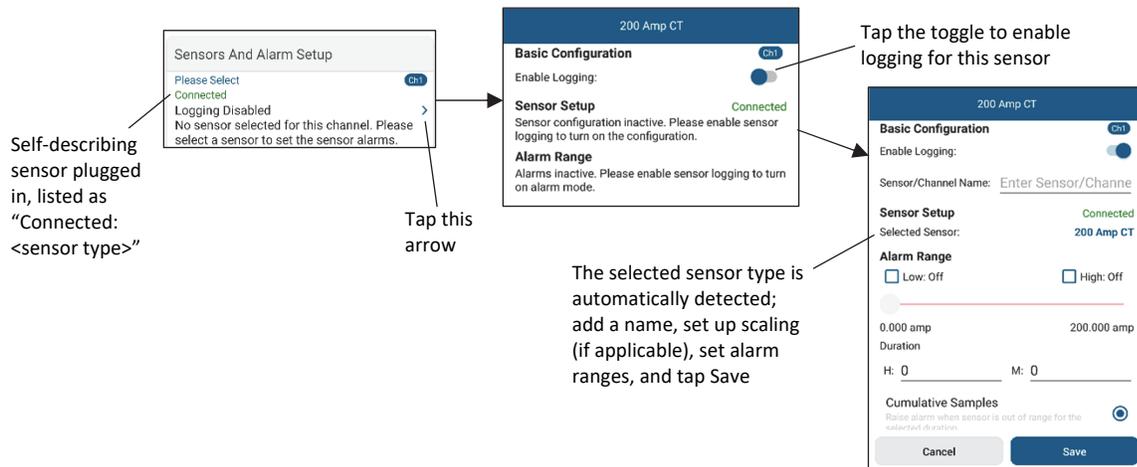
If the logger is deployed in an area where the CO₂ level does not go down to 400 ppm during the eight-day time period, then manual calibration should be performed regularly instead, or inaccurate CO₂ readings will be reported. If you plan on using auto calibration but the building will be occupied during the first day after logging begins, then you can use the manual calibration option as well. You can manually calibrate the logger immediately after logging begins and use auto calibration thereafter. **Note:** Once a manual calibration is performed, the 24-hour auto calibration is canceled, and an auto calibration will be performed eight days from the time the manual calibration occurred. (Restarting the logger resets the 24-hour/8-day auto calibration routine).

Refer to the manual www.onsetcomp.com/support/manuals/22504-mx1102a-manual for additional details on calibrating the logger.

MX1104/MX1105 Sensor Setup

When configuring external sensors for the MX1104 and MX1105 loggers, follow the instructions and guidelines in this section.

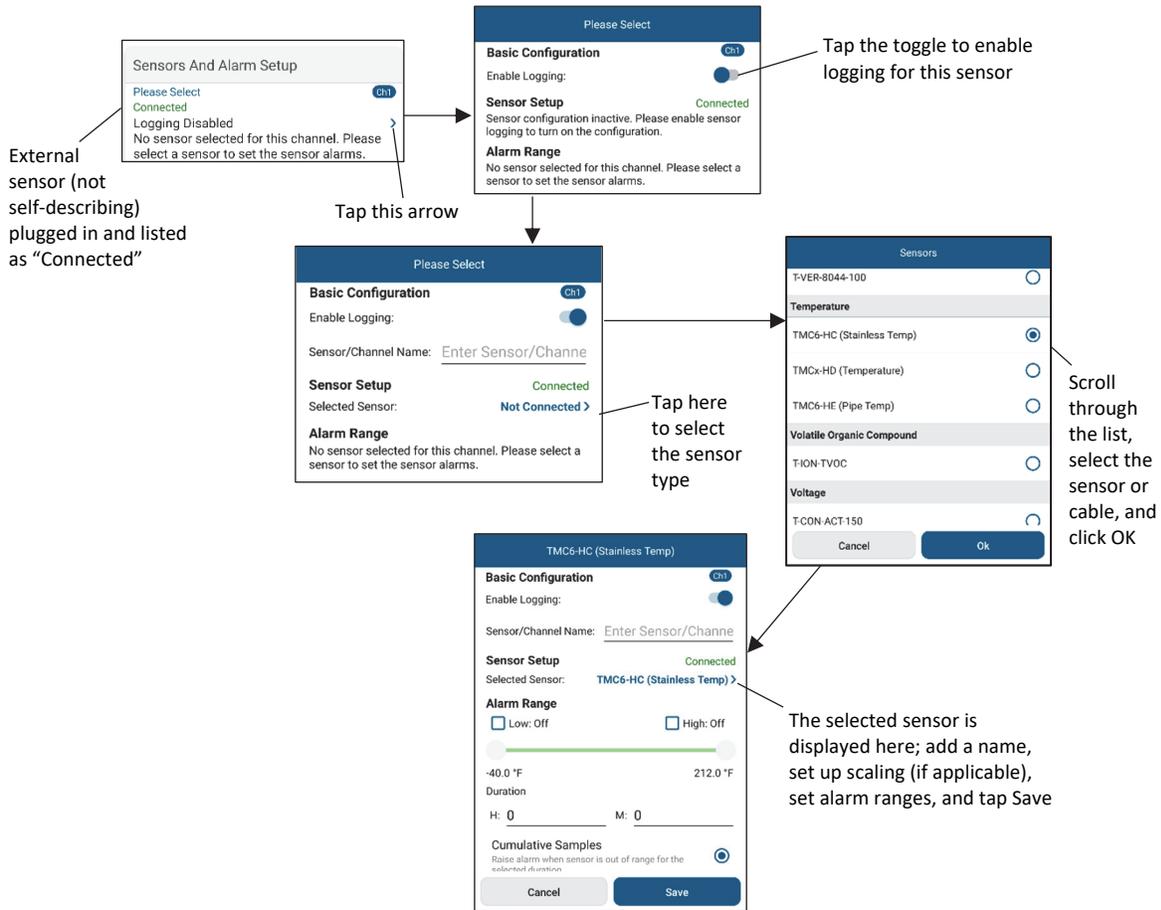
- **For self-describing sensors:** The sensor type will automatically be detected when you plug it in (i.e. 200 Amp CT as in the example below).



Sensors & Alarm Setup Setting

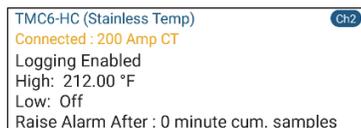
Description

- **For other external sensors:** The app will detect that a sensor is connected when you plug it in, but it will not automatically detect the sensor. You must select the correct sensor or cable type as shown in the following example.



Notes on all external sensors:

- If custom scaling is available, enter the Series Name, Unit, and values for High and Low under the selected sensor.
- For MX1104 loggers, the external sensor is channel 1. For MX1105 loggers, the sensor channel number is listed above the analog sensor port where the external sensor is connected.
- The app will display "Connected" in green text if the sensor is plugged in correctly and "Disconnected" in red text if a sensor has been unplugged. If "Sensor Error" in red text is displayed, make sure the sensor or cable is fully seated and installed properly in the logger analog sensor port.
- If you plug in a self-describing sensor in a port that was previously configured for a different sensor, "Connected: <sensor type>" is displayed in orange text until you reconfigure that channel for the new sensor.



- Make sure you select the correct sensor type in the app if you are not using self-describing sensors. If you select the wrong type, then incorrect data will be logged. In addition, if you unplug a sensor, the app will still display the last selected sensor type for that channel. If you plug in an external sensor other than a self-describing sensor, the previously selected

Sensors & Alarm Setup Setting	Description
	<p>sensor type will still be selected. Be sure to choose the correct sensor type for the new sensor that you plugged in.</p> <ul style="list-style-type: none"> • If you disconnect a sensor or if it is not fully inserted into the analog sensor port while the logger is logging, a warning icon appears on the LCD for that channel and the logger will beep once. Use the top button on the logger to view the channel with the warning, which also displays dashes instead of a valid current reading. Erroneous readings will be displayed in the app and logged depending on the logging interval while the sensor is disconnected (e.g., if a sensor is disconnected for 5 minutes and the logging interval is set to 1 minute, then there will be 5 erroneous data points while the sensor was disconnected). When the sensor is reconnected, the warning icon will clear, the correct value will replace the dashes for the channel on the LCD, and the correct readings will be logged. • Be sure to disable logging for any channels without external sensors installed. If logging is enabled for a channel without a sensor, then a warning icon appears on the LCD for that channel and the logger will beep once. • Do not swap out sensors or move sensors to empty ports while the logger is logging. Stop the logger before making any physical changes to the sensors. • Refer to the product manual at www.onsetcomp.com/support/manuals/23968-mx1104-and-mx1105-manual for additional details on installing external sensors.

Updating Water Parameters for an MX2001 Water Level Logger

To update the reference water level and water density for an MX2001 water level logger while the logger is logging:

1. Tap Devices.
2. Find the logger by searching or scrolling through the tiles and tap the tile to connect to the logger.
3. Tap .
4. Enter a new reference water level and select the unit type.
5. Select a different water density if needed or enter your own next to Manual Input.
6. Tap Save. Changes will take effect immediately. This will also result in reference water level and water density events in the HOBOb file.

Note: You can also edit the water parameters after the logger is downloaded by tapping  when viewing a HOBOb file. See *Using the HOBObfile Viewer* for details.

Calibrating an MX2501 pH and Temperature Logger

The MX2501 pH and temperature logger needs to be calibrated for accurate pH readings using pH 7, 4 and/or 10 buffers. To calibrate the logger, you will need:

- Deionized or distilled water and a squirt bottle to rinse the pH sensor.
- The logger with the pH electrode installed and the copper guard removed.
- Calibration solution (also called buffer solution) poured into beakers. You must calibrate the logger using two solutions: pH 7 and either 4 or 10. You also have the option to calibration using all three.

Notes before starting calibration:

- pH values of calibration buffers and samples will vary depending on their temperature. It is important that the logger is calibrated in buffers that have the same temperature as that of the sample. Refer to the chart on the calibration buffer bottles or in the logger manual for the effect of temperature on the buffer pH values.

- When placing the logger in a buffer solution, make sure the sensor end cap, temperature sensor, and closure cap are submerged in the solution.
- This section provides an overview on calibrating the logger. For additional details, refer to the product manual at www.onsetcomp.com/support/manuals/22511-mx2501-manual.

To calibrate the MX2501 logger:

1. Tap Devices. Push the button on the mounting end of the logger to wake it up (if necessary). Find the logger by searching or scrolling through the tiles.
2. Tap the tile to connect to the logger. You may be automatically prompted to calibrate the logger if pH electrode has never been calibrated, if the last calibration is more than seven days old, or if the firmware was updated. If you are not automatically prompted, then tap  .
3. Use a squirt bottle to rinse the pH sensor with deionized or distilled water.
4. Place the sensor end of the logger in the pH 7 solution and tap Start.
5. Once the pH reading is stable, tap Confirm.
6. Rinse the pH sensor with deionized or distilled water.
7. If you are using the pH 4 buffer, place the sensor end in the pH 4 solution and tap Start. If you are not using the pH 4 buffer, tap Skip and go to step 9.
8. Once the pH reading is stable, tap Confirm. Rinse the pH sensor with deionized or distilled water.
9. If you are using the 10 buffer, place the sensor end in the pH 10 solution and then tap Start. Once the pH reading is stable, tap Confirm. If you are not using the pH 10 buffer, tap Skip.
10. Verify that the slope and offset are acceptable, and tap Save. If the slope and offset are not acceptable, then tap the back arrow and repeat the calibration steps in this section as needed.

Important: After the calibration is complete, be sure to rinse the pH sensor with deionized or distilled water. Select any configuration settings as described in *Configuring a Logger*. **If you will not be deploying the logger within the next 10 minutes, attach the logger to the storage solution.**

Notes:

- The date of the last calibration, the slope and offset values, and the buffers used for the calibration are listed under the Deployment Information in the Configuration screen for reference.
- If the status message during calibration indicates the reading is invalid or it never stabilizes, try the following:
 - Make sure the sensor is in the correct buffer solution or try rinsing the sensor and restarting the calibration.
 - Remove the sensor from the calibration solution and clean it (refer to the product manual at www.onsetcomp.com/support/manuals/22511-mx2501-manual for details). Restart the entire calibration process.
 - Inspect the sensor to make sure it is not damaged. **Note:** There could be microcracks on the glass bulb of the electrode that may not be visible to the human eye.
 - Replace the pH electrode if it older than 6 months. A pH electrode has a 6-month expected life and will produce unstable readings if it is older than 6 months.
- If the reading reported in the app is acceptable for your deployment even though it is reported as unstable, you can tap Stop and then Confirm and proceed with the calibration.
- You can calibrate the logger while it is logging. After the calibration is saved, any new data logged will use the new calibration. Data logged before the new calibration was saved will use the old calibration data. If you do not want data in a single file to be based on more than one calibration, then stop the logger and read it out. You can then calibrate it and reconfigure it.

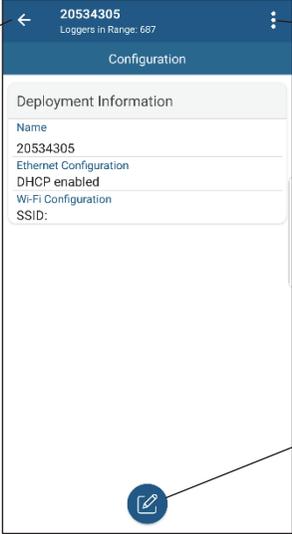
Configuring a Gateway

Note: These instructions require that the gateway is powered, completely booted up, and an Ethernet cable is already plugged in (if applicable). See the product manual at www.onsetcomp.com/support/manuals/23470-mxgtw1-gateway-manual for details on initial gateway setup.

To configure a gateway:

1. Tap Devices.
2. Find the gateway by searching or scrolling through the tiles.
3. Tap the tile to connect to the gateway.

4. Once connected, tap  at the bottom of the screen as shown below to configure the gateway. You can also view more information about the gateway (tap  in the upper right corner if applicable).



Tap this arrow to disconnect and return to the list of devices

Tap this icon to configure the gateway

On iPhones, iPads, or Android devices, tap here to view more details about the gateway, including the serial number, firmware version, and the information in the table at right. **Note:** These features are all on the main screen in the Windows version.



This icon:	Indicates:
	Connected via Ethernet
	Connected via Wi-Fi
	The network status is unknown
	The gateway is running
	The gateway is not configured
	There is a problem with the gateway; check the gateway settings
	The signal strength from the gateway to the phone, tablet, or computer

5. Enter a name for the gateway. If no name is entered, the gateway serial number will be used as the name.
6. If the Ethernet connection is using DHCP (dynamic IP addresses), then skip to step 7.
 - To set up Ethernet with static IP addresses, tap Ethernet Configuration, tap DHCP toggle to disable DHCP. Fill in the networking fields and tap Save. Consult your Network Administrator as needed.
 - To set up Wi-Fi, tap Wi-Fi Configuration, tap Current Network, or type a network name. Enter the password for the network and tap Save.
7. Tap  to save the new configuration settings to the gateway.

The gateway will regularly check loggers within range and upload data to HOBOLink (requires an active HOBOLink account; see *HOBOconnect Settings*). Loggers must be configured to upload data via the gateway (see *Configuring a Logger*). **Note:** MX100 series loggers are not supported by the gateway. Contact Onset Technical Support for questions on MX100 logger compatibility with the gateway.

Reading Out a Logger

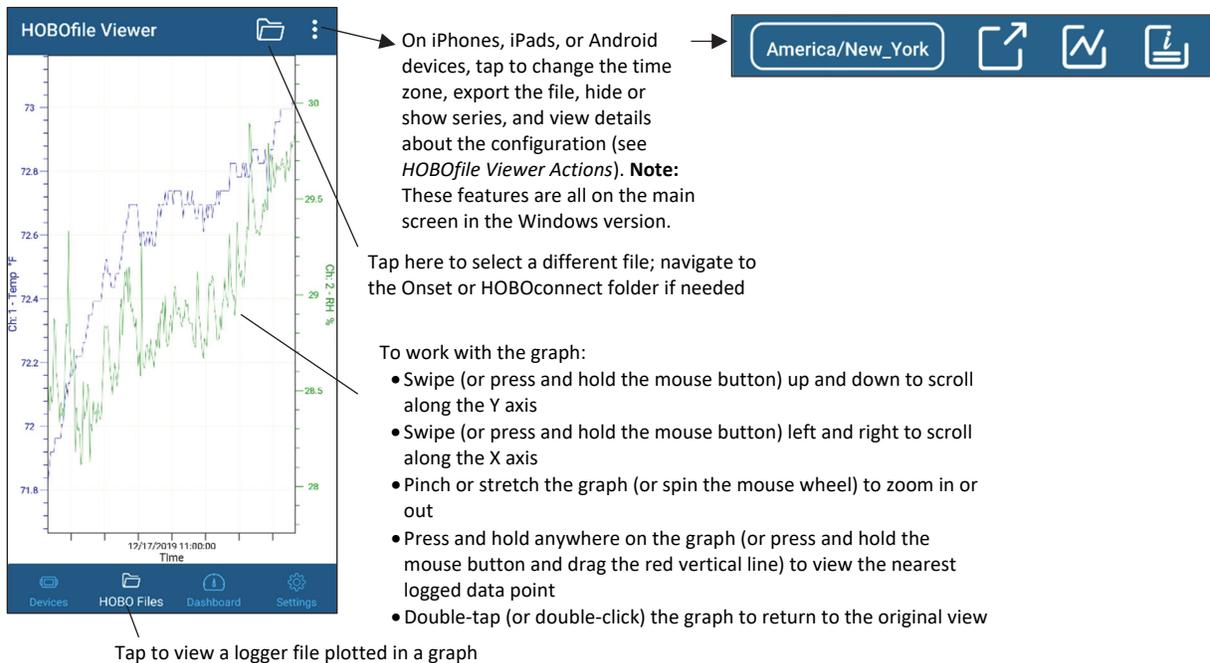
To read out or offload the data from a logger to a phone, tablet, or computer:

1. Tap Devices and then tap a tile with the logger to connect to it (wake up the logger if necessary or remove it from the water if applicable).
2. Once the logger is connected, tap  towards the bottom of the screen. Wait until the readout completes.
3. Tap HOBOb Files to view or export the data (see *Using the HOBObfile Viewer*).

Once the readout is complete, the data will be uploaded to HOBOblink automatically if the logger was configured to upload data via HOBObconnect (requires an active HOBOblink account; see *HOBObconnect Settings*). If the logger was configured to upload data via a gateway instead, then the gateway will continue uploading data regularly independently of this readout.

Using the HOBObfile Viewer

Use the HOBObfile Viewer to view and export data that has been offloaded from the logger. Tap HOBOb Files and select a file to open.



On iPhones, iPads, or Android devices, tap to change the time zone, export the file, hide or show series, and view details about the configuration (see *HOBObfile Viewer Actions*). **Note:** These features are all on the main screen in the Windows version.

Tap here to select a different file; navigate to the Onset or HOBObconnect folder if needed

To work with the graph:

- Swipe (or press and hold the mouse button) up and down to scroll along the Y axis
- Swipe (or press and hold the mouse button) left and right to scroll along the X axis
- Pinch or stretch the graph (or spin the mouse wheel) to zoom in or out
- Press and hold anywhere on the graph (or press and hold the mouse button and drag the red vertical line) to view the nearest logged data point
- Double-tap (or double-click) the graph to return to the original view

Tap to view a logger file plotted in a graph

HOBOfile Viewer and Actions

The following options are available when working with the HOBOfile Viewer (tap this icon  in the upper right corner first if applicable):

Tap this icon:

To do this:



This is the time zone setting in place on the phone, tablet, or computer when the logger was configured. Tap the time zone, select a different one, and tap Save to change the time zone that is displayed on the graph and used when exporting the data to XLSX or CSV. Note that a change to the time zone only applies while the file is open in the HOBOfile Viewer. If you close the file and reopen it, it will revert to the original time zone used when the logger was configured.



Tap to export and share the file that is currently open in the HOBOfile Viewer. Select one of the following:

- **XLSX.** This generates an Excel® file with data points from all series on one tab and logged events on a second tab.
- **CSV.** This generates a comma-separated values file with data points from all series and logged events on one spreadsheet.
- **HOBO.** Share the .hobo file that you have opened in the HOBOfile Viewer.
- **PNG.** This generates an image of the graph as it currently appears in the HOBOfile Viewer. Note that if you export to PNG more than once from the same HOBOfile Viewer, the existing .png file will be overwritten with the latest one. Therefore, if you want to save multiple views of the graph (e.g., one default view and one zoomed in view), make sure you share the first PNG you export before exporting another.

You can use export and share on Windows, Apple®, and Android devices.

On Apple devices, exported files are saved to the phone or tablet regardless of whether you share them immediately upon export. To access the files, navigate to the HOBOfile Viewer folder. Any exported XLSX, CSV, and PNG (image) files are stored in subfolders.

On Windows computers, select one of the Export options described above to save a file in the selected format to the computer at a location that you choose. You can then email or share that file as needed using your preferred method.

On Android devices, you must use export and share; external file access is prohibited by Android policy.



Tap here to show or hide sensors, channels, and logger events and tap OK. By default, logger events (such as Alarm Tripped or Alarm Cleared), derived series (such as dew point), and statistics are not displayed on the graph.



Tap here to view the configuration settings selected for the logger. **For MX2001 loggers only:** You can also edit the reference water level, water density, and reference time when tapping this icon. Under Deployment Information, tap Reference Water Level or Water Density to edit those settings in the Water Parameters screen. In the same Water Parameters screen, tap Reference Time and select a time associated with a logged data point and tap Save. Tap Save in the Water Parameter screen to apply these new settings to the HOBOfile.

Working with a Dashboard

Set up a dashboard to quickly view the latest readings from loggers within range of the phone or tablet without having to connect to them. This requires the logger to be awake with Bluetooth enabled (see *Configuring a Logger*).

To set up a dashboard:

1. Tap Dashboard.
2. Tap  in the upper right corner.
3. Set up the widget to add to your dashboard:

Select the type of widget: line graph or odometer.

Tap Add Channels.

Select the channels to display in the widget.

Tap to add another widget

Tap to delete the widget

Example of line graph widget

Example of odometer widget

Tap Next if you want to change the default channel name or tap Done.

Edit the name that will display on the dashboard for any of the channels and then tap Done.

Tap to edit the widget type or channels.

Measurements are updated every second when the logger is within range. Note that measurements displayed in the dashboard may differ from logged data points, which are recorded at the logging interval selected when configuring the logger. When a logger is out of range, the graph widget will not display any measurements and the odometer widget will display the most recent measurement from when the logger last communicated with the phone, tablet, or computer.

HOBObconnect Settings

Tap Settings to change the following settings in HOBObconnect:

Setting	Description
HOBOblink	<p>Connect a HOBOblink account to the app so that logged data can be automatically uploaded to www.hoboblink.com, where you can further analyze the data, set up dashboards, and more.</p> <p>Tap Connect Account. Enter your HOBOblink username and password and tap Connect. (If you don't have a HOBOblink account, tap Create New Account first).</p> <p>Once your account is connected, the following additional options are available:</p> <ul style="list-style-type: none"> • Tap Log Out if you want to disconnect your HOBOblink account from the app. You can then connect another account or reconnect to the same one. • Tap the Upload Data toggle to enable or disable the ability to automatically upload logged data from the gateway or the app. When this option is disabled, then the option to upload data will be grayed out when configuring the logger. When this option is enabled, then you can select whether to upload the data via the gateway or HOBObconnect when configuring the logger. • Tap the Wi-Fi Only toggle to enable or disable whether the app uses Wi-Fi only to upload data. If Wi-Fi Only is enabled, then the app will only upload data when a Wi-Fi connection is available. If Wi-Fi Only is disabled, then the app will use a cellular connection to upload data when a Wi-Fi connection is unavailable. • Readout Queue Status indicates whether there are any HOBOb files that were read out from loggers waiting to be uploaded to HOBOblink (i.e. the app was unable to connect to the internet and will try again later). Tap the status to see a list of current and pending file uploads.
User Settings	<ul style="list-style-type: none"> • Select either US or SI units. Any changes to units will take effect immediately throughout the app. The units displayed on the logger LCD (if applicable) will be updated the next time the logger is configured. • Tap to enable or disable Dark Mode, which changes the app color scheme. When Dark Mode is enabled, the app displays bright text on a black background. When Dark Mode is disabled, the app displays dark text on a white background.
Devices	<p>Clear My Devices List works in conjunction with the My Devices filter (see <i>Viewing Devices</i>) in which only the devices that your phone or tablet has connected to are shown in the Devices screen. Tap Clear My Devices List if you want to remove all the devices that you have connected to from the My Devices filtered view. You will then need to switch to a different filter to view any devices within range.</p>
Diagnostics & Troubleshooting	<p>These settings control the information that is gathered and shared with Onset.</p> <ul style="list-style-type: none"> • Tap the Share Diagnostics with Onset toggle to enable or disabled sharing of information about the software for troubleshooting and for future enhancements. • Tap the Enable Logging toggle and enable this setting only when directed by Onset Technical Support. When you enable this setting, the Share Logs with Onset option appears. Use this as directed by Onset Technical Support.

Frequently Asked Questions

The following questions can help with troubleshooting issues with the app. For additional help, tap About HOBObconnect in the settings to view a list of resources, or contact Onset Technical Support at 1-800-LOGGERS, 508-759-9500, or www.onsetcomp.com/support/contact.

Why isn't my logger appearing in the list of devices?

- The logger may need new batteries (if applicable). Symbols will appear on the logger LCD (if applicable) if the batteries have enough voltage remaining and are installed properly.
- The logger is not within range of the phone, tablet, computer, or computer dongle or something is obstructing the communication. Move closer to the logger. The range for successful wireless communication is approximately 30.5 m (100 ft) with full line-of-sight.
- The MX100, MX1104, MX1105, MX2200, MX2300, or MX2501 logger may be asleep. Press the button on the logger to wake it up.

- Remove the MX2203, MX2204, or MX2501 logger from the water if it was configured with Bluetooth Off Water Detect.
- Make sure Bluetooth is enabled in your phone, tablet, or computer settings.
- Check the filter settings to make sure the logger isn't being filtered out of view.

Why isn't my gateway appearing in the list of devices?

- The gateway may not be finished powering up. When plugged in for the first time, the gateway will not be ready to configure—and will not appear in the app—for several minutes.
- The gateway is not within range of the phone, tablet, computer, or computer dongle, or something is obstructing the communication. Move closer to the gateway. The range for successful wireless communication is approximately 30.5 m (100 ft) with full line-of-sight.
- Make sure Bluetooth is enabled in your phone, tablet, or computer settings.
- Check the filter settings to make sure the gateway isn't being filtered out of view.

I see my logger in the list of devices, but I can't connect to it. What can I do?

- Close the app and then reopen it.
- Power down the phone, tablet, or computer, and try connecting again once it powers back up.

I was configuring my logger and then lost the connection. Will my configuration settings be saved?

If you did not tap  before the connection was lost, then the configuration settings were not saved to the logger. Connect to the logger again and re-enter your settings.

How do I lock my logger so that no one else can configure it?

Connect to the logger, tap  in the upper right corner (if applicable), and tap . Enter a password and tap Set. The password will then be required any time another device attempts to connect to the logger. The device that configured the logger, however, will automatically retain the password so you do not have to type in a password each time that device connects to the logger.

How do I reset the password on a logger?

Connect to the logger, tap  in the upper right corner (if applicable), tap  , and tap Reset. You can also simultaneously press both the Start/Stop button and the Alarm/Stats button (MX1101) or Next/Clear button (MX1102A) on the top of the logger, or both the top and bottom button (MX1104 and MX1105) for 3 seconds. Press the button on the MX100, MX2200, MX2300, or MX2501 for 10 seconds or press the reset button between the batteries on the MX2001 logger.

An alarm was tripped on the logger. How do I clear it?

Visual alarms on the logger LCD (if applicable) and within the app (all models except MX100 and MX2001) are cleared based on the settings selected under "Maintain Visual Alarms Until" when configuring the logger. This means the visual alarm will clear when the logger is reconfigured, when the sensor is back within limits, or when the button on the logger is pressed (if applicable) depending on which option you selected. MX100 alarm indicators are only cleared when you reconfigure the logger.

If an audible alarm is sounding, press the button on the logger to stop it or connect to the logger and tap  (if applicable).

How do I offload my logger?

Connect to the logger and tap  . Once the readout is complete, tap HOBOb files to view or export the offloaded data.

It is taking more than a minute to read out my logger. Is this normal?

A logger with a full memory should take a minute or less to read out (all models except the MX1104 and MX1105). If the readout is taking longer than a minute, move the mobile device closer to the logger, within a few feet if possible. The further away the mobile device is from the logger, the longer the readout can take. MX1104 and MX1105 loggers have a larger memory capacity than other models so it may take a few minutes to read them out.

I zoomed in on a graph in the HOBObfile Viewer. How do I return it to the original view?

Double-tap the graph to return to the original view.

How do I view the individual data points in a list instead of a graph?

Export the file from the HOBObfile Viewer. Tap  in the top right corner (if applicable) and then tap . Select either XLSX or CSV, which creates a spreadsheet with all the data points.

How do I add or remove series or events from the graph?

In the HOBObfile Viewer, tap  in the top right corner (if applicable) and tap . Select or deselect the sensors, statistics, and events you wish to show or hide on the graph and tap OK.

Is there a way to copy all my data files to my computer?

You no longer have access to data files outside of HOBObconnect due to a Google Play Store policy. Use the Export and Share feature to have access to files outside of HOBObconnect.

For Apple devices, use Files to copy the files from the HOBObconnect folder to iCloud, which you can access from your computer. You can also use the File Sharing feature in iTunes on Windows® or Finder to transfer files to a Mac®.

For Windows computers, files are stored in your Documents folder under HOBObconnect. Copy the files to another folder.

My device is showing too many loggers. How can I view my devices only?

Tap  at the top left of the screen and select My Devices. Only the devices that your logger connected to will be shown in the list.

If my logger is configured to upload data to HOBOblink from a gateway, then will it also upload data to HOBOblink if I read it out with the app?

No. Data can only be uploaded to HOBOblink either by a gateway or by the app, not both. When you read out a logger that was configured to upload data from a gateway, then the file will be available in the app only and not uploaded to HOBOblink. The gateway will continue to monitor the logger and upload data regularly to HOBOblink regardless of when you read out the logger with app.

Attachment 4

New Temperature Data

Provided as DSS file.

Attachment 5

Swoffer Flow Data

Table 1
Dry Creek (3A) Upstream of Little Cow Creek Divergence Flow Rates

September 2024			December 2024			June 2025			August 2025		
Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)
23	1.4	0.84	38	0	0	NA	NA	NA	X	X	X
21	2.8	1.68	34.5	0.35	0.21	NA	NA	NA	X	X	X
19	3.6	2.16	31	1.9	1.14	NA	NA	NA	X	X	X
17	4.4	2.64	27.5	2.5	1.5	NA	NA	NA	X	X	X
15	4.4	2.64	24	2.4	1.44	NA	NA	NA	X	X	X
13	2.2	1.32	20.5	1.85	1.11	NA	NA	NA	X	X	X
11	2.8	1.68	17	1.6	0.96	NA	NA	NA	X	X	X
9	2.3	1.38	13.5	1.3	0.78	NA	NA	NA	X	X	X
7	2.6	1.56	10	0.95	0	NA	NA	NA	X	X	X
5	3.3	1.98	6.5	0.6	0	NA	NA	NA	X	X	X
3	2.8	1.68	3	-	-	NA	NA	NA	X	X	X
			0	-	-						
Average	2.96	1.78	Average	1.35	NA ²	Average	NA	NA	Average	X	X

Note

1. Measured at 60% of the total depth
2. The presence of a beaver dam at this location prevented water flow and precluded valid Swoffer measurements to be collected.

-: No measurable current
NA: No measurable current due to beaver dam
X: Equipment failure prevented current measurements

Table 2
Little Cow Creek (2A) Upstream of Cow Creek Divergence Flow Rates

September 2024			December 2024			June 2025			August 2025		
Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)
42			52	0	-	2.75	0.45	0.8	X	X	X
38	1.1	0.66	47.5	1.75	1.05	7.5	0.5	0.847	X	X	X
34	1.1	0.66	43	2.8	1.7	11.5	0.88	1.227	X	X	X
30	1.3	0.78	38.5	2.75	1.65	15.5	1.03	0.218	X	X	X
26	1.7	1	34	2.25	1.35	19.5	0.9	0.825	X	X	X
22	2.3	1.38	29.5	1.4	0.84	23.5	0.84	1.217	X	X	X
18	3	1.8	25	1	0.6	27.5	0.85	0.949	X	X	X
14	4.1	2.46	20.5	0.9	0.54	31.5	0.69	1.073	X	X	X
10	3.3	1.38	16	0.9	0.54	35.5	0.53	0.633	X	X	X
6	2.1	1.76	12	0.7	0.42	40.25	0.94	0.041	X	X	X
			7.5	0.5	-						
Average	2.22	1.32	Average	1.36	0.97	Average	0.76	0.78	Average	X	X

Notes:
1. Measured at 60% of the total depth
-: No measurable current
X: Equipment failure prevented current measurements

Table 3
Cow Creek (1A) Downstream of USGS Gage Flow Rates

September 2024			December 2024			June 2025			August 2025		
Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)	Wading Rod Base Distance (Feet)	Depth (Feet)	Water velocity (cfs)
25	0	0	100	1.2	0.72	6.5	0.59	0.493	X	X	X
32	0.8	0.48	96	0.5	0.3	18.5	0.88	1.026	X	X	X
39	1.6	0.96	92	0.4	0.24	27	1.15	1.159	X	X	X
46	1.7	1.02	88	1.4	0.8	33	1.27	1.281	X	X	X
53	1.9	1.14	84	1.65	1.0	39	1.58	1.474	X	X	X
60	1.7	1.02	80	2.1	1.2	45	1.65	1.783	X	X	X
67	3	1.8	76	1.7	1.0	51	1.48	1.894	X	X	X
74	3.1	1.86	72	1.3	0.8	57	1.69	1.828	X	X	X
81	1.5	0.9	68	1.6	1.0	63	1.39	1.621	X	X	X
88	0.25	0	64	1.8	1.1	69	0.99	1.531	X	X	X
95	2.5	1.5	60	1.9	1.15				X	X	X
			56	1.8	1.1				X	X	X
			52	1.8	1.1				X	X	X
			48	1.7	1.0				X	X	X
			44	1.7	1.0				X	X	X
			40	1.5	0.9				X	X	X
			36	1.2	0.7				X	X	X
			32	1	0.6				X	X	X
			28	0.5	0.03				X	X	X
Average	1.64	0.97	Average	1.41	0.83	Average	1.27	1.41	Average	X	X

Notes:
1. Measured at 60% of the total depth
X: Equipment failure prevented current measurements