Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California

CDFW-IFP-002

Version 2

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California Department of Fish and Wildlife
Instream Flow Program
West Sacramento, California

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Abbreviations and Acronyms

Term	Definition
cfs	Cubic feet per second
Department	California Department of Fish and Wildlife
FH950	Hach FH950 portable velocity flow meter
FPA	Fixed-period averaging
ft	Feet/foot
ft^2	Square feet
ft/s	Feet per second
GPS	Global Positioning System
HP	Headpin
IFP	Instream Flow Program
in.	Inches/inch
LBWE	Left bank wetted edge
Model 2000	Marsh-McBirney Model 2000 Flo-Mate portable velocity flow meter
RBWE	Right bank wetted edge
SOP	Standard operating procedure
TP	Tailpin
USB	Universal Serial Bus
USGS	United States Geological Survey

Conversions

1 cfs ≈ 2.83×10^{-2} m^3/s
1 inch = 2.54 cm
1 foot = 0.3048 m

Use of product names in this document is for descriptive purposes and does not imply endorsement by the Department of Fish and Wildlife or the Instream Flow Program.

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Introduction

This standard operating procedure (SOP) represents the California Department of Fish and Wildlife (Department) Instream Flow Program’s (IFP’s) protocol for collecting discharge measurements in wadeable streams using the Hach FH950 (FH950) velocity flow meter (flow meter) and United States Geological Service (USGS) top-setting wading rod. Except in unusual circumstances, the IFP rarely uses a Marsh-McBirney Flo-Mate Model 2000 flow meter; operating procedures specific to that meter can be found in the Appendix. This SOP was revised to reflect the use of the newer flow meter and replaces the original 2013 SOP. This SOP also includes general guidelines based on those of the USGS (Rantz and others 1982; Turnipseed and Sauer 2010) for collecting velocity measurements and calculating stream discharge measurements that are not particular to a specific flow meter model. The SOP may be used in conjunction with other IFP SOPs.

Guidelines are provided for:

- Calibration and general care of the FH950 and top-setting wading rod
- Site selection of discharge cross sections
- Use of the FH950 and top-setting wading rod to collect velocity measurements at various depths
- Performing discharge calculations

Scope of Application

This SOP provides the procedural reference for Department staff conducting discharge measurements in wadeable streams, when site conditions and research objectives indicate that measurement of discharge is appropriate. The SOP is intended as an informational resource for other state and federal agencies, non-governmental organizations, private contractors, and other organizations throughout California. The Department encourages SOP users to contact the IFP with any questions or for assistance with project planning.

Section 1: Site Selection and Field Considerations

Before collecting discharge data, select a site with characteristics that support accurate flow measurements. Discharge measurements may be collected at any time of year if the guidelines outlined in *Section 1.1 Site Selection* are met. Consider the general quality of field conditions for taking a discharge measurement following USGS guidelines (Rantz and others 1982; Turnipseed and Sauer 2010). The Department *highly recommends* that trained and experienced instream flow practitioners conduct or oversee all fieldwork and data analysis.

Note: Crew safety is of paramount importance; only perform fieldwork when crews can safely survey.

1.1 Site Selection

The first step in taking an accurate discharge measurement is to select a cross section with suitable characteristics (Turnipseed and Sauer 2010). A desirable cross section is depicted in Figure 1. The USGS (Rantz and others 1982; Turnipseed and Sauer 2010) and FH950 user manual (Hach 2018) recommend that cross sections with the following characteristics be chosen whenever possible:

- The cross section is located in a channel that is reasonably straight with flow perpendicular to the cross section.
- The streambed along the cross section is stable and free of large rocks, aquatic vegetation, undercut banks, or other physical obstructions that create eddies, slack water, or turbulence that could influence velocity measurements.
- The channel form along the cross section is roughly parabolic, trapezoidal, or rectangular in shape and is as uniform as possible (i.e., no pronounced thalweg).
- The water surface is smooth with steady, uniform, non-varying flow conditions along the cross section. No more than 10% (ideally no more than 5%) of the total flow can be in any one cell, defined as the distance between two adjacent vertical measurement points (referred to as stations) on the cross section.

- The cross section will ideally be located close to a site of interest (e.g., gaging station, bed elevation profile) if the goal is to develop a relationship between the field discharge measurement and data from the site of interest. This will help avoid the impacts of inflows from intervening drainage areas or diversions between the cross section and site of interest.
- The wetted length of the cross section is wide enough to take velocity measurements at a minimum of 20 stations (using the FH950, the minimum allowable distance between stations is 0.25 ft).
- The cross section is not located immediately downstream of sharp bends or vertical drops that would negatively impact velocity measurements by unevenly distributing flow along the cross section.

Figure 1. A discharge cross section exhibiting desirable site characteristics.

Locating an ideal cross section that satisfies all the previously listed characteristics can be difficult, and the practitioner will have to use their best professional judgement and experience to find the most suitable site (Rantz and others 1982).

Note: While selecting discharge sites, beware of redds (i.e., salmonid, lamprey) that may be present. If cross section placement would intersect with the presence of a redd, then it is not suitable for discharge measurements at that time.

1.2 Measurement Considerations and Limitations

The instream flow practitioner must consider many factors when conducting discharge measurements. Suggested USGS (Rantz and others 1982; Turnipseed and Sauer 2010) considerations include:

- Measuring section: consider the conditions along the cross section that could affect the accuracy of the discharge measurement. These conditions include uniformity of depths, composition and uniformity of the streambed (e.g., silt, gravel, cobble, detritus), presence of bridge pilings or other obstructions, and the ability to accurately measure depth.
- Velocity conditions: consider the factors present that could affect the accuracy of measuring velocity. Such conditions could include: smoothness of velocity, very slow or very high velocity, turbulence, factors that could affect the vertical distribution of velocity, and the method used to measure velocity (i.e., one-point, two-point, or three-point method as outlined in *Section 2.6 Connecting the FH950 to the Top-Setting Wading Rod*).
- Spacing of stations: the goal is to have cell discharges that are roughly equal along the cross section. Use a minimum of 20 stations per cross section, where each cell has no more than 10% of the total discharge (ideally, less than 5%). Using fewer cells may reduce the accuracy of the discharge measurement. Take the first and last wetted measurements as near to each bank as possible.
- Changing stage: rapidly changing stage can affect the accuracy of the discharge measurement. A temporary staff gage is used to determine if flow conditions

change during data collection. If the stage is changing during data collection, wait for conditions to stabilize before retaking discharge.

- Ice: the presence of ice generally decreases the accuracy of velocity and depth measurements. Ice affects the velocity distribution and may negatively affect equipment.
- Wind: wind can affect accuracy of discharge measurements by changing the vertical distributions of velocities and may make it difficult to determine the angle of the current. Wind can also produce waves that complicate depth readings. The effect of wind on the velocity profile lessens as depths and stream velocities increase.

The practitioner must consider the potential impacts on velocity measurement accuracy for all the factors listed in this section, as well as the combined impacts of those factors. Ambient factors (e.g., weather) that could impact measurement accuracy must also be considered and noted on the datasheet.

Section 2: Equipment Preparation, Calibration, and Use

This section describes how to prepare, calibrate, and operate the FH950 and USGS top-setting wading rod, and the additional equipment needed to take a discharge measurement. The procedures for inspection, calibration, and setup must be followed before continuing to *Section 3 Field Data Collection Procedures*. This SOP only covers use of the FH950 (and the Marsh-McBirney Model 2000 in the Appendix). If using a different flow meter, follow the guidelines for calibration and operation provided by the manufacturer.

2.1 Equipment List

Bucket (for flow meter calibration; non-metallic)

Calculator

Camera

Clamp (to keep sensor still during calibration)

Clipboard

FH950 user manual (Hach 2018)

FH950 flow meter (with charger, spare battery pack, and thumb screws)

Fiberglass measuring tape (100' to 300' recommended)

Field datasheets or notebook (Rite in the Rain® or another water-resistant brand)

Flagging tape

Gloves

GPS unit

Hammer (for staff gage and rebar)

Loppers or pruning shears (if needed for vegetation removal)

Pencils

Permanent marker

Rebar (two per cross section; 2.5' to 4.0' length recommended) and safety caps

Phillips head screwdriver (for battery replacement)

Staff gage (to monitor change in flow conditions)

USGS top-setting wading rod (in English units)

Field datasheets can be found at:
https://www.wildlife.ca.gov/Conservation/Watersheds/Instream-Flow

2.2 Care and Maintenance of the FH950

The FH950 comprises an electromagnetic sensor, sensor cable, and flow meter. Water passing through the magnetic field produced by the sensor and into the sensor electrodes generates a voltage. The magnitude of the voltage is proportional to the velocity of the water passing through the magnetic field (Ott Hydromet 2015). The meter then uses this voltage to calculate velocity.

Take precaution before each field event to ensure that the sensor, sensor cable, and velocity meter are in good working condition and that there is no damage to any component. The FH950 sensor has four electrodes, three on the front and one on the left side towards the rear of the sensor. General practice is to not touch the front or sides of the FH950 sensor since foreign substances such as oils or sunscreen can be transferred to the sensor. Foreign substances can change the conductivity of the sensor electrodes and cause inaccurate or noisy velocity readings. Only handle the back of the sensor. If the meter has been used in muddy water, staff believe the sensor electrodes have been covered by a foreign substance, or if the meter readings become unexpectedly noisy, clean the sensor before use. To remove any coatings from the sensor electrodes, ensure that the sensor is disconnected, wash the sensor using dish soap and water or isopropyl alcohol, then gently wipe with a clean cloth (Hach 2018).

The FH950 is powered by a rechargeable battery with a life of up to 18 hours of use (Hach 2018). Charge the FH950 battery before fieldwork. Bring an extra rechargeable battery pack into the field in case the meter's battery stops operating. Replacement of the battery pack requires a Phillips head screwdriver.

2.3 Calibration of the FH950

Calibrate the FH950 each day before data collection begins by performing a zero adjustment. The following calibration procedure for the FH950 is consistent with the manufacturer's user manual (Hach 2018). The FH950 user manual (Hach 2018) should be read prior to operating the flow meter. Keep a copy of the manual readily available in the field.

To calibrate the FH950, perform the following steps each day before fieldwork begins:

Step 1: Suspend the sensor in a non-metallic bucket with water at least 6 in. deep (Figure 2). To suspend the sensor, the meter cable can be clamped or otherwise secured to a piece of rebar placed over the bucket. Leave at least 3 in. between the sensor and the sides and bottom of the bucket.

Note: Avoid touching the electrodes on the sensor.

Figure 2. Setup for calibration of FH950 flow meter showing the sensor cable suspended from rebar and secured with a clamp.

Step 2: Wait until water in the bucket is *completely still* before continuing with the calibration process and proceeding to Step 3.

Step 3: When the water is still, power on the FH950. From the Main Menu screen on the FH950, select ***Setup***, then select ***Velocity Calibration*** (Figure 3).

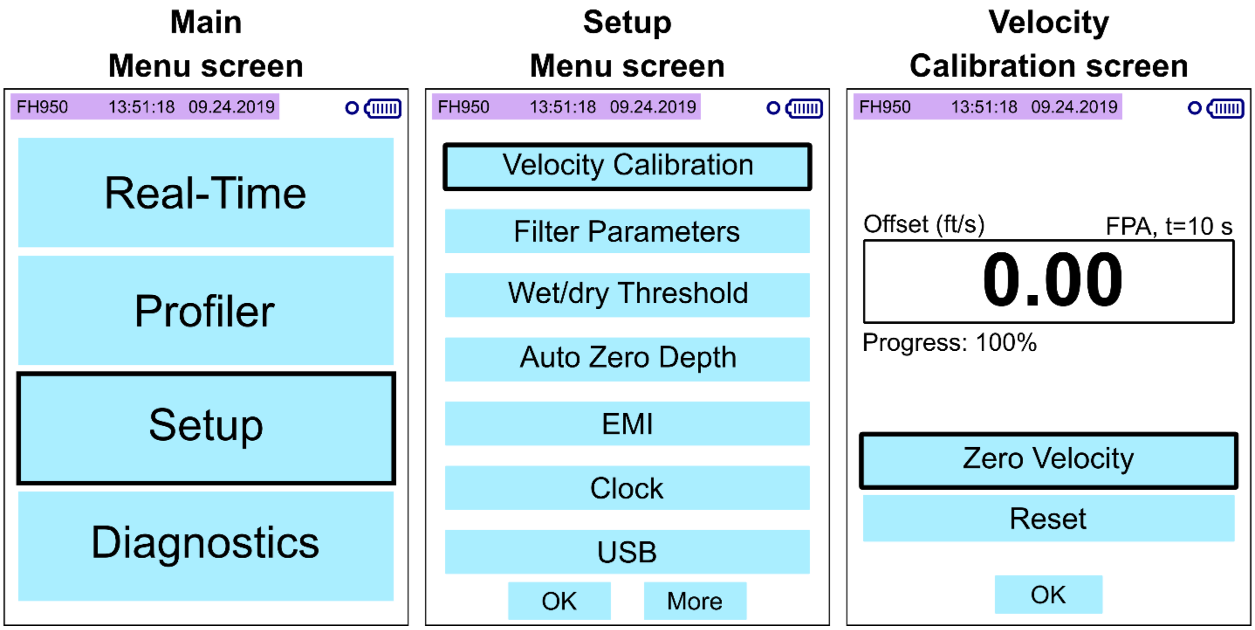

Figure 3. FH950 screens encountered during the calibration process.

Step 4: Allow the meter to complete one velocity cycle (the default is 10 seconds and cannot be changed) If the meter reads 0.00 feet per second (ft/s), select ***OK***. If the water is still and the meter does not read 0.00 ft/s, wait for the reading to stabilize and select ***Zero Velocity*** (Figure 3), then select ***OK***. The zero stability of this instrument is +/- 0.05 ft/s (Hach 2018). If a velocity of greater than +/- 0.05 ft/s is read, repeat the zero adjust process starting with Step 2. Consider cleaning the sensor electrodes or ensuring the water inside the bucket is completely stable before repeating the process.

Note: The FH950 must be properly calibrated before data collection can begin.

2.4 Checking the System Settings on the FH950

Before using the FH950 for data collection, check the system settings to ensure that the proper measurement time interval, station entry method, discharge computation method, units of measurement, and measurement resolution are selected. To check or adjust the system settings, perform the following steps each day before fieldwork begins:

Step 1: From the Main Menu screen, select ***Setup***, then select ***Filter Parameters***. From the Filter Parameters screen, select ***Main Filter***, then select ***Fixed-Period Avg.*** (FPA). Make sure that the time allotted for FPA is between 20 and 40 seconds, depending on the stream conditions and research objectives, then select ***OK***. See the project lead for more guidance on FPA, if necessary.

Step 2: The distance between stations can be entered into the FH950 through either a fixed (automatic) or non-fixed (manual) method. The IFP uses the non-fixed method to allow the FH950 operator to select the distance between stations and ensure that any non-uniform velocity and/or depth profiles can be captured. This also allows any minor flow obstructions to be avoided. To set the station entry method, go to the Main Menu, select ***Setup***, then select ***More*** at the bottom of the screen, and lastly select ***Station Entry***. Select ***Non-fixed***, then select ***OK***. On the following screen for measurement reference, select ***Top***.

Step 3: The FH950 can calculate discharge using two different computational methods: the mid-section method and the mean-section method. In a comparative study, Young (1950) determined the mid-section method saves time and produces results that are most similar to the true discharge. For this reason, the IFP uses the mid-section computational method. The FH950 default setting is the mid-section method because it gives more exact results than the mean-section method (Hach 2018). To set the calculation method, go to the Main Menu, select ***Setup,*** then select ***More*** at the bottom of the screen, and lastly select ***Flow Calculation***. Select ***Mid-section***, then select ***OK***.

Step 4: To set the units of measurement, go to the Main Menu***,*** select ***Setup***, then select ***More*** at the bottom of the screen, and lastly select ***Units***. From the Units screen, select ***English*** units of measurement, then set the units for flow (cubic feet per second; cfs), depth (ft), and area (square feet; ft^2), by selecting the corresponding boxes. Lastly, select ***OK***.

Step 5: To set the velocity measurement resolution go to the Main Menu, select ***Setup***, then select ***More*** at the bottom of the screen, and lastly select ***Measurement Resolution***. Select ***0.01***, then select ***OK***.

2.5 Inspection of the USGS Top-Setting Wading Rod

Inspect the top-setting wading rod carefully before each field event to ensure that all parts are secure and in working order (e.g., the bumper is working properly, and the base is securely attached). Ensure that the top-setting rod being used has measurements in English units. The top-setting wading rod is a ½” hexagonal stainless-steel rod with a replaceable, threaded aluminum base plate and an anodized aluminum handle. A ⅜” aluminum suspension rod, referred to as the setting rod, is attached to the hexagonal rod by a sliding support at the bottom and at the handle. The setting rod slides up and down the hexagonal rod with the sensor attached to the sliding support. If any part of the top-setting wading rod is not functioning properly, repair or replace the part since the accuracy of measurements could be jeopardized.

Note: The top-setting wading rod must be inspected and in good working condition before data collection can begin.

2.6 Connecting the FH950 to the Top-Setting Wading Rod

Before collecting discharge data, attach the FH950 to the top-setting wading rod as follows:

Step 1: Place the mounting hole of the FH950 sensor over the mounting shaft on the bottom end of the sliding setting rod (Figure 4).

Step 2: Hand tighten the thumb screw clockwise to secure the sensor onto the mounting shaft. Do not overtighten the thumb screw.

Note: The FH950’s thumb screw has the ability to detach from the sensor body; bring extra thumb screws into the field.

Figure 4. FH950 sensor attached to the top-setting wading rod.

2.7 Determining Cell Depth and Width for Collection of Velocity Measurements Along the Cross Section

The FH950 measures velocity and is used in conjunction with the top-setting wading rod to estimate site-specific discharge measurements. The depth that the FH950 sensor is set at for each individual measurement along the cross section is based upon the depth of the water column at that station (see Figure 6). The fixed, hexagonal portion of the top-setting wading rod measures depth and has graduations of 0.10 ft. Double graduation marks represent increments of 0.50 ft, and triple graduation marks represent increments of 1.00 ft. The hexagonal rod scale is read to the nearest 0.05 ft by visually estimating between the 0.10 ft graduation increments. This is particularly important when measuring shallow depths. The minimum operable water depth for the FH950 sensor is 0.15 ft.

The vernier setting scale on the handle of the top-setting wading rod is used in conjunction with the sliding setting rod to position the sensor at the correct depth to measure velocity. The vernier scale has graduation marks of 0.10 ft (Figure 5) and the graduation marks on the setting rod represent increments of 1.00 ft. When the foot scale on the setting rod and vernier scale are aligned to match the water depth observed on the hexagonal rod, the sensor is automatically set to six-tenths depth (0.6 depth) from the water surface. In accordance with USGS (Turnipseed and Sauer 2010) protocol:

For depths measuring 0.15 to 2.45 ft: One measurement is taken at 0.6 depth from the water surface (see Figure 6). This is referred to as the one-point method. Set the sensor at 0.6 depth by lining up the foot scale on the setting rod with the vernier scale on the top-setting wading rod handle. For example, if the depth is 0.90 ft, line up the 0 on the setting rod foot scale with the 9 on the top-setting wading rod handle's vernier scale (Figure 5). In this example, the sensor will automatically be set to measure velocity at a depth of 0.36 ft.

Figure 5. Top-setting wading rod handle showing vernier scale set at 0.90 ft.

For depths greater than or equal to 2.50 ft: Two depth measurements are taken and averaged. Measurements are taken at two-tenths depth (0.2 depth) and eight-tenths depth (0.8 depth) from the water surface (Figure 6). This is referred to as the two-point method. For example, if the depth is 2.50 ft, set the wading rod as follows:

- To measure at 0.2 depth from the water surface, double the depth observed on the hexagonal rod (i.e., 2.50 ft x 2 = 5.00 ft) and set the scale to 5.00 ft by aligning the "5" on the setting rod foot scale with the "0" on the vernier scale of the wading rod handle. This will automatically set the sensor to measure velocity at a depth of 2.00 ft.
- To measure at 0.8 depth, divide the depth by two (i.e., 2.50 ft / 2 = 1.25 ft) and set the scale to 1.25 ft by aligning the "1" on the setting rod foot scale half way between "2" and "3" on the vernier scale of the wading rod handle. This will automatically set the sensor to measure velocity at a depth of 0.50 ft.
- If the two-point method produces a non-standard or inverted-velocity profile, take an additional velocity measurement at 0.6 depth. This is referred to as the three-point method. A non-standard velocity profile is one in which the velocity at the 0.8 depth is greater than that at the 0.2 depth, or in which the velocity at the 0.2 depth is greater than twice that of the 0.8 depth (Turnipseed and Sauer 2010). The velocity at the 0.6 depth is then averaged along with the average velocities of the 0.2 and 0.8 depths to determine the velocity at that station along the cross section.

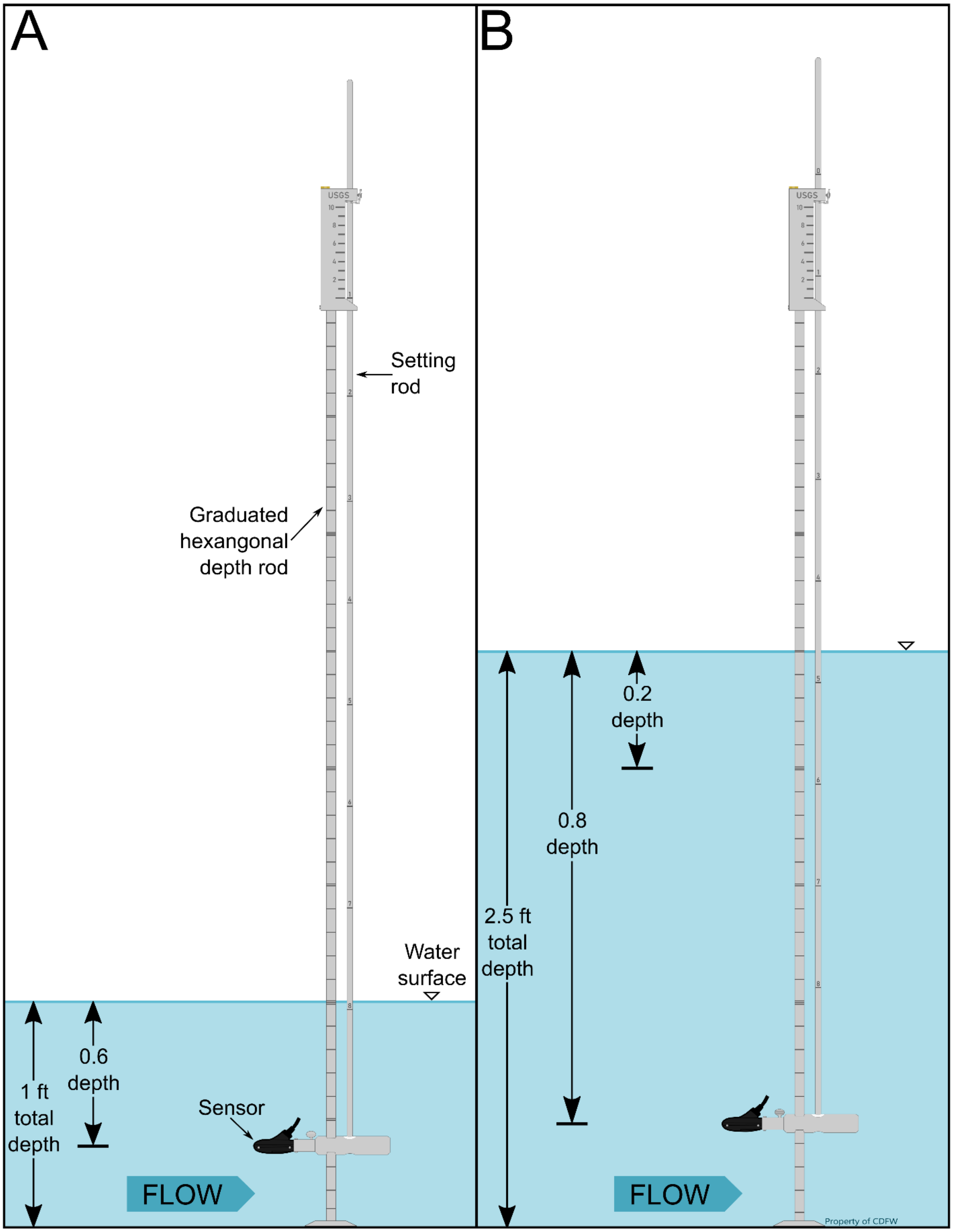

Figure 6. Illustration showing how the sensor depth is set using the top-setting wading rod for (A) depths of less than 2.50 ft and (B) depths greater than or equal to 2.50 ft. Figure adapted from Marsh-McBirney Inc (1990).

A minimum of 20 vertical cell measurements are required for each discharge cross section (see Figure 9). The cross section must have no more than 10% (ideally less than 5%) of the total discharge occurring in any one cell or between any two stations along the cross section.

As a rough guide, the distance between each station can be determined by the length of the cross section, where the maximum distance between each station would be the length of the cross section divided by 20 (to account for the minimum number of required cell measurements). Equal distances between stations can be maintained if the depth and velocity at each station is relatively uniform and the discharge is evenly distributed across the stream (Rantz and others 1982). Shorter distances between stations may be necessary if the depth or velocity is varying along the cross section. Due to the width of the sensor, and to avoid overlapping velocity profiles in adjacent cells, the distance between stations can be no less than 0.25 ft.

Section 3: Field Data Collection Procedures

Once a site is identified for discharge measurements as described in *Section 1 Site Selection and Field Considerations*, and the field equipment is prepared as described in *Section 2 Equipment Preparation, Calibration, and Use*, proceed with the field data collection procedures.

3.1 Discharge Cross Section Setup

Step 1: During discharge data collection at a site, set up the cross section. Mark the discharge cross section with a rebar headpin (HP) on the left bank (looking upstream) and a tailpin (TP) on the right bank. Install the HP and TP rebar into the streambank beyond the wetted edge of the water. If the study objectives require additional discharge measurements at different flows, consider placing the HP and TP rebar further up on the streambank to accommodate higher flows.

Step 2: Insert a temporary staff gage (Figure 7) into the substrate near the stream's edge. Install the staff gage near the cross section within visual range, but out of the way of foot traffic so that it is not disturbed during data collection. The staff gage is used to determine if the flow is stable or fluctuating.

Figure 7. A staff gage used to monitor change in flow conditions.

Step 3: If permitted, flag the cross section with site information above the high-water mark on vegetation, and on the HP and TP if the cross section will be measured at different flows.

Step 4: Take a GPS waypoint at the HP for reference and to ensure future repeatability, if needed.

Step 5: Once the HP and TP are installed on the streambank, stretch a measuring tape from HP to TP and ensure that the tape is taut.

Step 6: If the cross section has been modified in any way to provide more reliable velocity measurements, allow the flow conditions to stabilize before beginning. Once velocity measurements have begun, do not alter the cross section.

Step 7: After the measuring tape is installed, photograph the cross section. Photographs are helpful for documenting and comparing wetted cross section widths and channel conditions between measurements. Take photos in the following sequence for consistency and ease of managing the photos:

A. Photograph the cross section while standing upstream on the left bank above the HP, aiming camera across the stream towards the TP. Include the survey measuring tape in the image.

B. Photograph the cross section while standing upstream on the right bank above the TP, aiming camera across the stream towards the HP. Include the survey measuring tape in the image.

C. Photograph the entire longitudinal profile of the cross section from HP to TP (while standing both downstream and upstream of the cross section). Record the photo numbers in the appropriate field on the datasheet.

3.2 Data Collection Using the FH950

Step 1: Populate the datasheet header information, including the stream name, site information, FH950 unit ID number, data evaluator full name, data recorder full name, GPS waypoint, and photo range.

Step 2: Record the staff gage water surface height in the “Gage Start” field of the datasheet and record the start time.

Step 3: If the discharge measurement is being repeated at an established cross section, clearly note on the datasheet any changes to the stream channel in the area around the cross section. Changes to the stream channel between measurements (e.g., due to downstream migration of woody debris or sediment) can impact the hydraulics of the stream and affect the stage-discharge relationship.

Step 4: Record the total HP to TP distance in the appropriate field on the datasheet. Next, record the distances from the HP to the wetted edges of the stream at the left bank wetted edge (LBWE) and the right bank wetted edge (RBWE), looking upstream.

Step 5: Press the FH950 power button to turn on the unit. Check the system settings of the FH950 as described above in *Section 2.3 Calibration of the FH950*.

Step 6: From the Main Menu screen, select ***Profiler***. Then enter the evaluator's name and select ***OK***. Next, select ***Stream*** and enter the stream name or reach that is being measured, then select ***OK***. The next screen will prompt the user to enter the stage reference; enter "100" and select ***OK***.

Step 7: Starting on the left bank, the first station for the discharge measurement is the LBWE. From the Profiler Menu screen, select ***Edge/Obstruction***, then select ***Left*** (Figure 8). This will automatically set the depth and velocity to zero. Next, enter the distance to the station by selecting ***Dist. to Vertical***; enter the distance between the HP and the LBWE and select ***OK*** (Figure 8). Then select the ***Next*** at the bottom of the screen to move onto the second station.

Profiler Station Menu screen | **Profiler Edge/ Obstruction screen** | **Profiler Distance to Vertical screen**

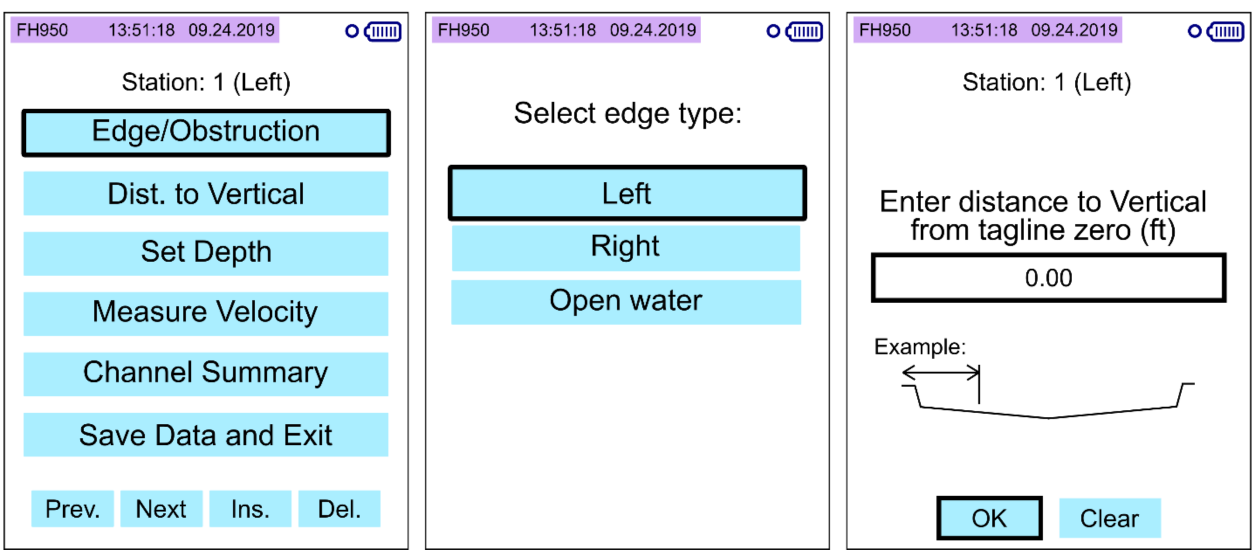

Figure 8. FH950 screens encountered during Step 7.

Step 8: At the first wetted measurement station, select ***Edge/Obstruction***, then select ***Open Water***. Next, select ***Dist. to Vertical*** and enter the distance between the measurement station and the HP, then select ***OK***. Record the distance in the appropriate field on the datasheet.

Note: The first and last wetted measurements must be taken as close as possible to the LBWE and RBWE, respectively, due to the use of the mid-section calculation method (see Section 4 Discharge Calculations).

Step 9: Stand at least 3 in. downstream of the measuring tape that marks the cross section and at least 1.50 ft from the top-setting wading rod to avoid interfering with velocity measurements (Rantz and others 1982). At each station, place the top-setting wading rod onto the streambed, check that it is plumb, and record the depth from the hexagonal rod in the appropriate field on the datasheet.

Step 10: Select ***Set Depth*** from the Profiler Menu and enter in the stream depth at the station being measured, then select ***OK***. Adjust the vernier scale on the top-setting wading rod to the proper depth as described in *Section 2.6 Connecting the FH950 to the Top-Setting Wading Rod*.

Note: Use of the vernier scale on the top-setting wading rod automatically adjusts the sensor to the correct measurement depth. *If the vernier scale does not perfectly match on both sides of the top-setting wading rod, use the same side throughout data collection for consistency.*

Step 11: From the Profiler Menu screen, select ***Measure Velocity***. Ensure that the FH950 sensor is facing directly into the flow at the station, and that there is no debris impeding or obstructing the sensor from detecting flow at that station.

A. If the depth of the stream is less than 2.50 ft, select ***One Point***, then select ***0.6***. The FH950 will then display the depth at which to set the sensor. This depth can be ignored. Properly adjusting the top-setting wading rod using the vernier scale will automatically set the sensor to the correct depth. Next, select ***Capture***, and wait for the FPA time to elapse, then select ***OK***. Lastly, select ***Main***. The FH950 will then return to the Profiler Menu screen for that station. Select ***Next*** to continue to the next station.

B. If the depth of the stream is greater than or equal to 2.50 ft:

a) Select ***Two Point***, then select ***0.2***. Ensure that the vernier scale on the top-setting rod is adjusted to the proper depth as described in *Section 2.6*. This measurement will represent the velocity at 0.2 depth from the water surface. Next, select ***Capture***, and wait for the FPA time to elapse, then select ***OK***.

b) Next, select ***0.8***. Ensure that the vernier scale on the top-setting rod is adjusted to the proper depth as described in *Section 2.6*. This measurement will represent the velocity at 0.8 depth from the water surface. Next, select ***Capture***, and wait for the FPA time to elapse, then select ***OK***. Lastly, select ***Main***. The FH950 will then return to the Profiler Menu screen for that station. Select ***Next*** to continue to the next station.

Note: Because the sensor needs to be oriented directly into the flow at the station, it may not face directly upstream.

Step 12: Record the velocity measurement to the nearest 0.01 ft/s in the appropriate field on the datasheet.

Step 13: Repeat steps 9 through 12 until the RBWE is reached.

Step 14: Once the RBWE is reached, select ***Edge/Obstruction*** on the Profiler Menu and select ***Right***. This will automatically set the depth and velocity to zero. Next, select ***Dist. to Vertical*** and enter the distance between the HP and the RBWE, then select ***OK***. Record the RBWE in the appropriate field on the datasheet.

Step 15: Check the channel summary to ensure that each cell along the cross section has a partial discharge of less than 10% of the total discharge (ideally, less than 5%). From the Profiler Menu, select ***Channel Summary***. The total cross-section discharge will be shown in a box at the top of the screen and a bar graph will be shown at the bottom of the screen. Select the ***Cont.*** (i.e., Continue) box at the bottom of the screen to toggle the bar graph between the depth, velocity, and percent discharge of cells along the cross section. If any changes need to be made (e.g., because the top-setting wading rod was not adjusted properly or a cell had a partial discharge of 10% or greater), such as adding stations, checking entries, or retaking velocity measurements, follow the directions provided in the note below. Then, select ***Save Data and Exit*** and name the file as desired. The FH950 only allows for eight characters in the file name. Lastly, select ***OK***.

*Note: If stations need to be added or deleted, options for **Prev.**, **Next**, **Ins.**, and **Del.** appear at the bottom of the Profiler Menu screen. Use **Prev.** (i.e., Previous) and **Next** to navigate to the station where you would like to insert (i.e., **Ins.**) or delete (i.e., **Del.**) a station. For example, to insert a new station between Stations 3 and 4, select **Prev.** until the Profiler Menu display screen shows information for Station 3, and then select **Ins**. The new station will be named Station 4 and subsequent stations will be renamed sequentially. To delete Station 3, navigate to that station and select **Del.**, then select **Yes** to confirm, and lastly select **OK** to return to the Profiler Menu. If the Channel Summary reports an unexpectedly large partial discharge, check the Depth and Distance to Vertical entries by navigating to the station(s) of concern using **Prev.** and **Next** and editing as necessary by referring to the field datasheet. To retake a velocity reading, select **Measure Velocity** at the station of concern.*

Step 16: After data collection is complete, check the staff gage to ensure that flow conditions remained stable during the survey. Review the datasheet(s) to ensure completeness prior to removal of survey equipment.

Section 4: Discharge Calculations

The IFP recommends that, in accordance with USGS policies, discharge be calculated in the field as a check on measurements and data transcription. Field discharge calculations also provide an opportunity to adjust FH950 station entries (e.g., if the station depth or the distance to vertical is entered incorrectly) or to take additional measurements if errors are found (e.g., if the partial discharge of a cell is greater than or equal to 10%). After fieldwork is completed, discharge data are reviewed before entering the data electronically in the office using an Excel spreadsheet. Once all field data are entered and checked according to quality assurance procedures, discharge may be calculated using the Discharge SOP Data Forms workbook available at https://wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/SOP. Directions for both hand and electronic calculations are included in this section.

Discharge may be calculated for each cross section by entering the data from the field datasheet into the Discharge Data Input File in the Discharge SOP Data Forms workbook. This Excel spreadsheet automatically calculates the average cell velocity, cell width, and the partial discharge of each cell. The partial discharge of each cell is then summed to estimate the total discharge of the cross section.

4.1 Details of Discharge Calculations

Discharge is calculated using the width, depth, and velocity data from each station along the cross section. Do not round recorded depth and velocity measurements on the datasheet (e.g., if the velocity is 1.99, do not round to 2.0). Similarly, do not round the partial discharges for individual cells. Rounding may result in inaccurate total discharge values. The total discharge can be rounded after all partial discharges have been summed.

The IFP uses the mid-section method to calculate the cell width. This method assumes that the average velocity at each station is representative of the average cell velocity (Turnipseed and Sauer 2010). In accordance with the mid-section method, the width of a cell is calculated as half of the change in distance from the preceding station plus half of the change in distance to the next station (Figure 9). This is equivalent to half the distance between adjacent stations, rather than simply the distance from the preceding station.

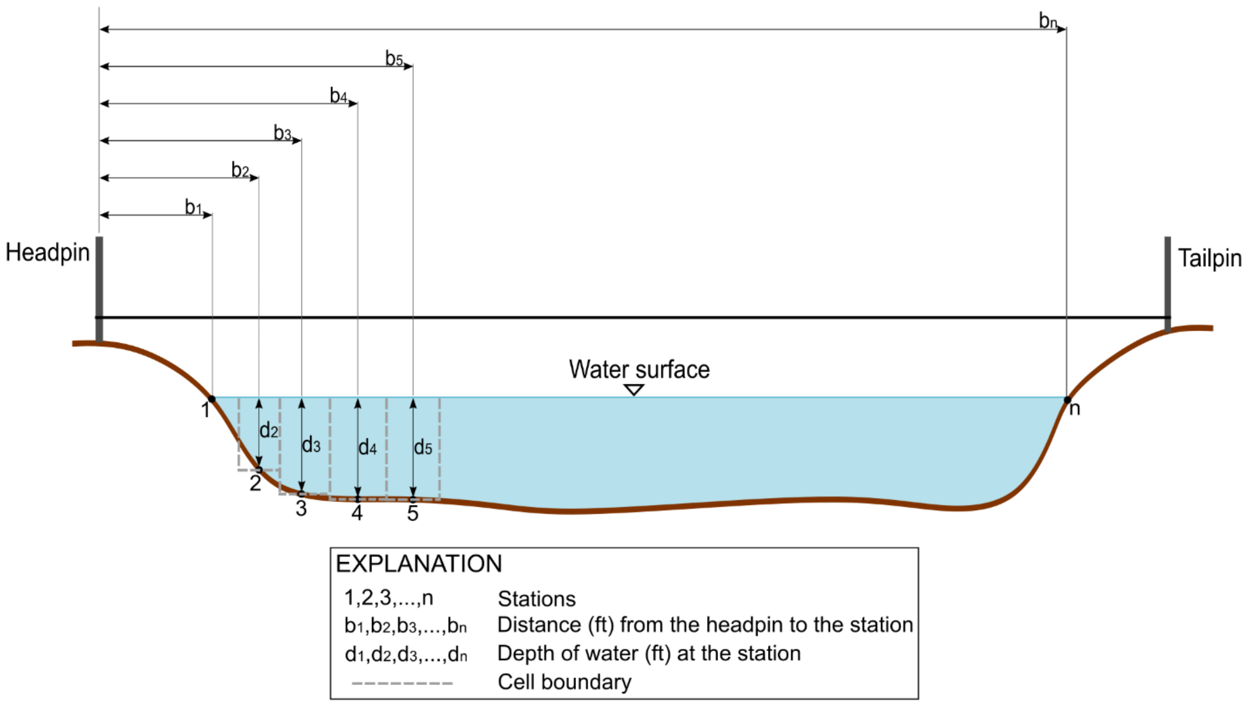

Figure 9. Cross section showing vertical measurement cells and the distances used to determine cell width using the mid-section method. Headpin, tailpin, and measuring tape are indicated over the cross section. Figure adapted from Turnipseed and Sauer (2010).

Equation 1: Cell Width

In Figure 9, the width of the first cell (Station 2) would be:

$$Width_2 = \frac{(Distance_2 - Distance_1) + (Distance_3 - Distance_2)}{2}$$

or

$$Width_2 = \frac{(Distance_3 - Distance_1)}{2}$$

$$Width_2 = \frac{(b_2 - b_1) + (b_3 - b_2)}{2} = \frac{(b_3 - b_1)}{2}$$

Where:

b = distance from HP to measurement station (ft)

Equation 2: Partial Discharge of a Cell

The partial discharge of each cell is determined by multiplying the width, depth, and velocity:

$$q = w * d * v$$

Where:

q = partial discharge of cell (cfs)
w = cell width (ft)
d = station depth (ft)
v = average station velocity (ft/s)

For example, if the cell width is 1.00 ft, the station depth is 1.20 ft, and the velocity is 1.30 ft/s, the partial discharge of the cell would be calculated as follows:

Partial discharge = 1.00 ft x 1.20 ft x 1.30 ft/s = 1.56 cfs

Note: If two velocities were taken at a station (at a depth greater than or equal to 2.50 ft), use the average velocity.

Equation 3: Total Discharge of a Cross Section

The total discharge of a cross section can then be estimated by summing each cell's partial discharge value:

$$Q = q_1 + q_2 + q_3 + \cdots q_n$$

Where:

Q = total discharge of cross section (cfs)
q_1 = partial discharge of the first cell (cfs)
q_2 = partial discharge of the second cell (cfs)

q_3 = partial discharge of the third cell (cfs)

n = total number of cells in cross section

Note: Partial discharge calculations resulting in negative values must be included in the sum (i.e., subtracted).

Equation 4: Check for Exceedance of 10% of the Total Discharge

To check what percent of the total cross-section discharge is in the cell with the largest partial discharge value, use the following equation. This calculation is used to check if the discharge in any one cell exceeds 10%.

$$\text{Maximum cell discharge \%} = \frac{q_{largest}}{\text{Q}} * 100$$

Where:

$q_{largest}$ = largest partial discharge found in any one cell (cfs)

Q = total discharge of cross section (cfs)

Section 5: FH950 Data Management

Data collected in the field and saved on the FH950 can be downloaded to a computer. The data storage on the FH950 operates like a removable hard drive and is read only. The following steps originate from the FH950 user manual (Hach 2018):

Step 1: Set the FH950 to USB mass storage mode. Go to the Main Menu, select ***Setup***, then select ***USB,*** and lastly select ***Mass Storage***.

Step 2: Connect the FH950 to the computer using the USB cable provided with the meter (USB A-Type to 5-pin USB Mini-B). See the Hach user manual to locate the USB connection port.

Step 3: Power on the FH950 and navigate to a drive labeled “PVM” on the computer using File Explorer or the like. Stream profiler data files are stored in tab separated variable (.TSV) format in a directory labeled “P.” Right-click or double-click to export the desired files to Microsoft Excel.

*Note: if the computer displays a warning message indicating that the device needs to be formatted before use, ignore the warning and **do not** format the device. In most instances, unplugging the USB cable from the computer and reconnecting with the FH950 power turned on will solve the issue.*

Step 4: To delete data files from the FH950, go to the Main Menu, select ***Diagnostics***, then select ***Delete Files***.

Glossary

Term	Definition
Cell	The distance between two adjacent stations (i.e., vertical measurements) along the discharge cross section (also referred to as “segments”, “sections”, or “partial areas” in other sources).
Station	Measurement locations for depth and velocity taken along the discharge cross section (also referred to as “observation points” or “verticals” in other sources).
Vernier Scale	A small, moveable graduated scale that slides along a main scale of a measuring instrument. The small scale is calibrated to indicate fractional divisions of the main scale.

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Young, K. B. (1950). A comparative study of mean-section and mid-section methods for computation of discharge measurements. 53-277: 52. Available: https://pubs.er.usgs.gov/publication/ofr53277.

Appendix: Discharge Measurements Using a Marsh-McBirney Model 2000

Introduction

This Appendix presents the operating procedure for the Marsh-McBirney Flo-Mate Model 2000 (Model 2000) velocity flow meter (flow meter) where it differs from the operation of the FH950. While both meters can be used to collect discharge measurements, the FH950 is the primary flow meter used by the IFP for data collection. This section covers only the care, preparation, and use of the Model 2000 flow meter. A list of additional equipment needed for discharge measurements, considerations for site selection and cross section setup, use of the top-setting wading rod, and guidance for discharge calculations are covered in the main document.

Guidelines are provided for:

- Calibration and general care of the Model 2000
- Use of the Model 2000 to collect velocity measurements

Section 1: Equipment Preparation, Calibration, and Use

This section describes how to prepare, calibrate, and use the Model 2000. The procedures for inspection, calibration, and setup must be followed before continuing with field data collection.

1.1 Care and Maintenance of the Model 2000

Like the FH950, the Model 2000 is an electromagnetic flow meter. Take precaution to ensure that the sensor, sensor cable, and flow meter are in good working condition and that there is no damage to any component. The Model 2000 has three electrodes on the front of the sensor. General practice is to avoid touching the sensor electrodes since foreign substances such as oils or sunscreen can be transferred to the sensor and cause inaccurate or noisy velocity readings. General practice is to not touch the front end of the Model 2000 sensor. Only handle the back of the sensor. If the flow meter has been used in muddy water, staff believe the sensor electrodes have been covered by a foreign substance, the meter readings become unexpectedly noisy, or an error (i.e., “Err”) message is displayed, disconnect and clean the sensor using water and dish soap and then gently wipe with a clean cloth (Marsh-McBirney Inc 1990). If the meter is still producing noisy velocity readings, gently wipe the sensor electrodes with 1000-grit or greater wet-dry sandpaper.

The Model 2000 is powered by two, size D batteries. Battery life with alkaline batteries is approximately 25 to 30 hours (Marsh-McBirney Inc 1990). Bring an extra set of batteries into the field in case the meter’s batteries need to be replaced. Replacement of the batteries requires a Phillips head screwdriver. If the batteries must be replaced while measurements are underway, recalibrate the meter and note prominently on the datasheet. If there is no physical way to recalibrate the meter in the field, note this on the field datasheet for the measurements taken after the batteries were replaced. Staff should bring a small, non-metallic bucket with them into the field for calibration purposes.

1.2 Calibration of the Model 2000

Calibrate the Model 2000 each day before data collection begins by performing a zero check to ensure the water is still, then a zero adjust. The following procedure for the Model 2000 is consistent with the manufacturer’s user manual (Marsh-McBirney Inc 1990). The Model 2000 user manual (Marsh-McBirney Inc 1990) should be read prior to operating the flow meter. Keep a copy of the manual readily available in the field.

To calibrate the Model 2000, perform the following steps each day before fieldwork begins:

Step 1: Suspend the sensor in a non-metallic bucket with water at least six inches deep. To suspend the sensor, the meter cable can be clamped or otherwise secured to a piece of rebar placed over the bucket (Figure 1). Leave at least three inches between the sensor and the sides and bottom of the bucket.

Note: Avoid touching the electrodes on the sensor.

Figure 1. Setup for calibration of a Model 2000.
This example shows a sensor suspended from rebar and stabilized by a hammer.

Step 2: Wait until the water in the bucket is *completely still* before continuing with the calibration process and proceeding to Step 3.

Step 3: To perform a zero check, power on the Model 2000 and let the meter run through one complete cycle of velocity measurements to check that the water is not moving.

Step 4: To begin the zero adjust process, press the ***STO*** (i.e., Store) and ***RCL*** (i.e., Recall) buttons simultaneously. Make sure the sensor *does not move* when the buttons are pressed on the Model 2000. The screen will read “3” (Figure 2).

Figure 2. Model 2000 screen displayed when beginning the zeroing process.

Step 5: Press the down arrow key ( ) on the meter three times to set the display to 0.

Note: The down arrow must be pressed within five seconds or the display will report “Err” (i.e., Error). Turn the meter off and repeat the process starting with Step 3 if the error code appears.

Step 6: The Model 2000 will immediately count down on the display from 32 to 0. The meter will automatically turn off after the zero adjust process is complete.

Step 7: Turn the meter back on *without moving* the sensor. Allow the meter to run through one complete velocity cycle. The zero stability of this instrument is +/- 0.05 ft/s (Marsh-McBirney Inc 1990). If a velocity of greater than +/- 0.05 ft/s is read, repeat the zero adjust process starting with Step 2. Consider cleaning the sensor electrodes or ensuring the water inside the bucket is completely stable before repeating the process.

Note: The Model 2000 must be properly calibrated before data collection can begin.

1.3 Checking the System Settings on the Model 2000

Before using the Model 2000 for data collection, check the system settings to ensure that the desired units of measurement and measurement time interval are selected. To check the system settings, perform the following steps each day before fieldwork begins:

Step 1: Power on the Model 2000.

Step 2: Check that the velocity units are in ft/s. If the units are not in ft/s, toggle between velocity units by simultaneously pressing the ***ON/C*** and ***OFF*** buttons until display reads ft/s.

Step 3: Check that the meter is using Fixed Point Averaging (FPA). The velocity is averaged over a set time period when using FPA. At the end of this time period, the display shows the updated averaged velocity. The FPA display shows a time bar underneath the velocity output that indicates the amount of time remaining in the averaging period. To toggle between FPA and time constant filtering, simultaneously press the up and down arrow buttons on the meter.

Step 4: After the display indicates FPA, it will show the number of seconds used for the FPA time period. Check that the FPA time period is between 20 to 40 seconds, depending on the stream conditions and research objectives. If it is not, press the up or down arrows until the display reads the desired time.

1.4 Connecting the Model 2000 to the Top-Setting Wading Rod

Before collecting discharge data, attach the Model 2000 to the top-setting wading rod as follows:

Step 1: Place the mounting hole of the Model 2000 sensor over the mounting shaft on the bottom end of the sliding setting rod.

Step 2: Hand tighten the thumb screw clockwise to secure the sensor onto the mounting shaft (Figure 3). Do not overtighten the thumb screw.

Figure 3. Tightening a Model 2000 thumb screw with sensor attached to the mounting shaft of the top-setting wading rod.

Section 2: Field Data Collection Procedures

Once a site is identified for discharge measurements and the field equipment is prepared, proceed with the field data collection procedures.

To collect data with the Model 2000, first press the ***ON/C*** button. The Model 2000 collects data in real-time and will start measuring velocity for the desired time interval as set in *Section 1.3 Checking the System Settings on the Model 2000*. When the time bar on the bottom of the Model 2000 display reaches the end of prescribed time interval, it will start over and the average velocity will be displayed. Record this velocity measurement in the appropriate field on the datasheet.

References

Marsh-McBirney Inc (1990). Flo-Mate Model 2000 portable flowmeter instruction manual. Marsh-McBirney, Inc, Frederick, MD. Rev. D, 11/00: 45.