

Chapter IV. STREAM FLOW MEASUREMENT PROTOCOLS

Section A. Sum of Partial Discharges Method

Most discharge measurements of stream flow are made by the **Sum of Partial Discharges Method** using a velocity-meter because it is adaptable to a wide range of velocities and is practically unlimited as to the total discharge that can be measured. Essentially, the method consists of: 1) measuring the velocity of flow in and the area of each of several parts of a cross-sectional transect; 2) computing the discharge in each part as the product of the velocity and area; and 3) summing the partial discharges to obtain the total.

The usual method of making a discharge measurement is explained in **Figure 39**, which shows the cross-section of a channel.

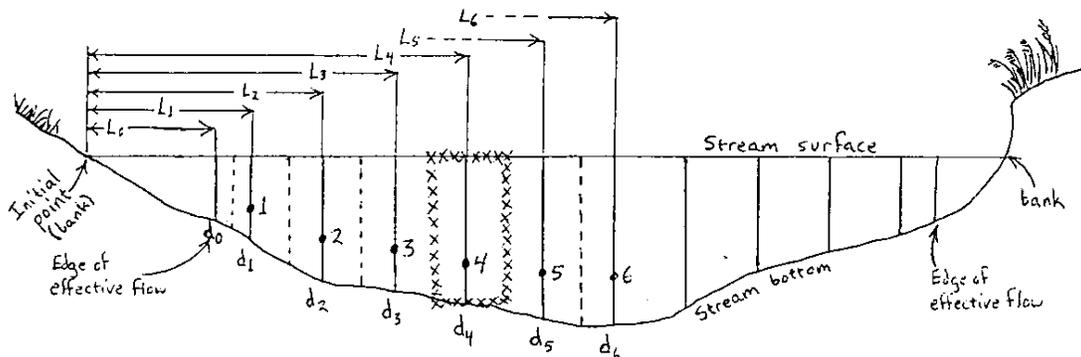


Figure 39. Cross section of stream channel

Where:

1, 2, 3, 4, 5, 6, - Velocity measurement points or observation points for each of six consecutive partial sections.

$L_1, L_2, L_3, L_4, L_5, L_6$ – Distances in feet from the initial point to each observation point's vertical intersect with the stream surface for each of six consecutive partial sections.

$d_1, d_2, d_3, d_4, d_5, d_6$ – Depths of water in feet at the observation points in each of six consecutive partial sections.

Dotted lines indicate the boundaries of partial sections.

The depth of water is measured by rod at observation points 1, 2, 3, 4, and so forth. The velocity of the water is measured by velocity meter at each of these locations at such position(s) in the vertical that the mean velocity in the vertical is obtained.

The discharge past a partial section is computed by the following equation:

Equation 2. Calculation of Partial Stream Flow or Discharge

$$Q_4 = (V_4)(d_4) \frac{[(L_5 - L_3)]}{2}$$

Where:

Q_4 = discharge or flow in cubic feet per second through partial section 4 (**see Figure 39 above**)

V_4 = mean velocity in feet per second at location 4.

d_4 = depth of water in feet and tenths of a foot (not inches) at location 4.

L_3, L_4, L_5 = distances in feet and tenths of a foot (not inches) from the initial point to locations 3, 4, and 5, respectively (**see Figure 39 above**).

The area defined by this formula is that shown by the X-line highlight around location 4 in **see Figure 39 above**.

The summation of the discharges for all the partial sections is the total discharge of the stream. It is calculated by computer program once all the necessary data are plugged into the program (**See Table 8 on page 144 for an example of the data used to calculate the total discharge or flow**).

Materials and Supplies

1. Wading Rod – for measuring stream depth and setting depth of flow measuring device.
2. Marsh-McBirney Flo-Mate – for measuring water velocity.
3. Tape Measure in feet and tenths – for determining the distance between velocity readings.
4. Flow Record Sheets (**see Chapter II. Section C. Part 2. APPENDIX #1 - Stream Discharge (Flow) on page 78**) – for recording data collected along the flow transect and for final computation of flow.
5. Pencils.
6. Lightweight clipboard with string to drape around neck - for carrying flow sheet while keeping both hands free to manipulate wading rod and Flo-mate.

Part 1. Operation and Maintenance of Flo-Mate

For a more complete description of the Care and Operation of the Model 2000 Marsh-McBirney Flo-Mate, consult the instruction manual provided by the manufacturer (see **Figure 40 below**).

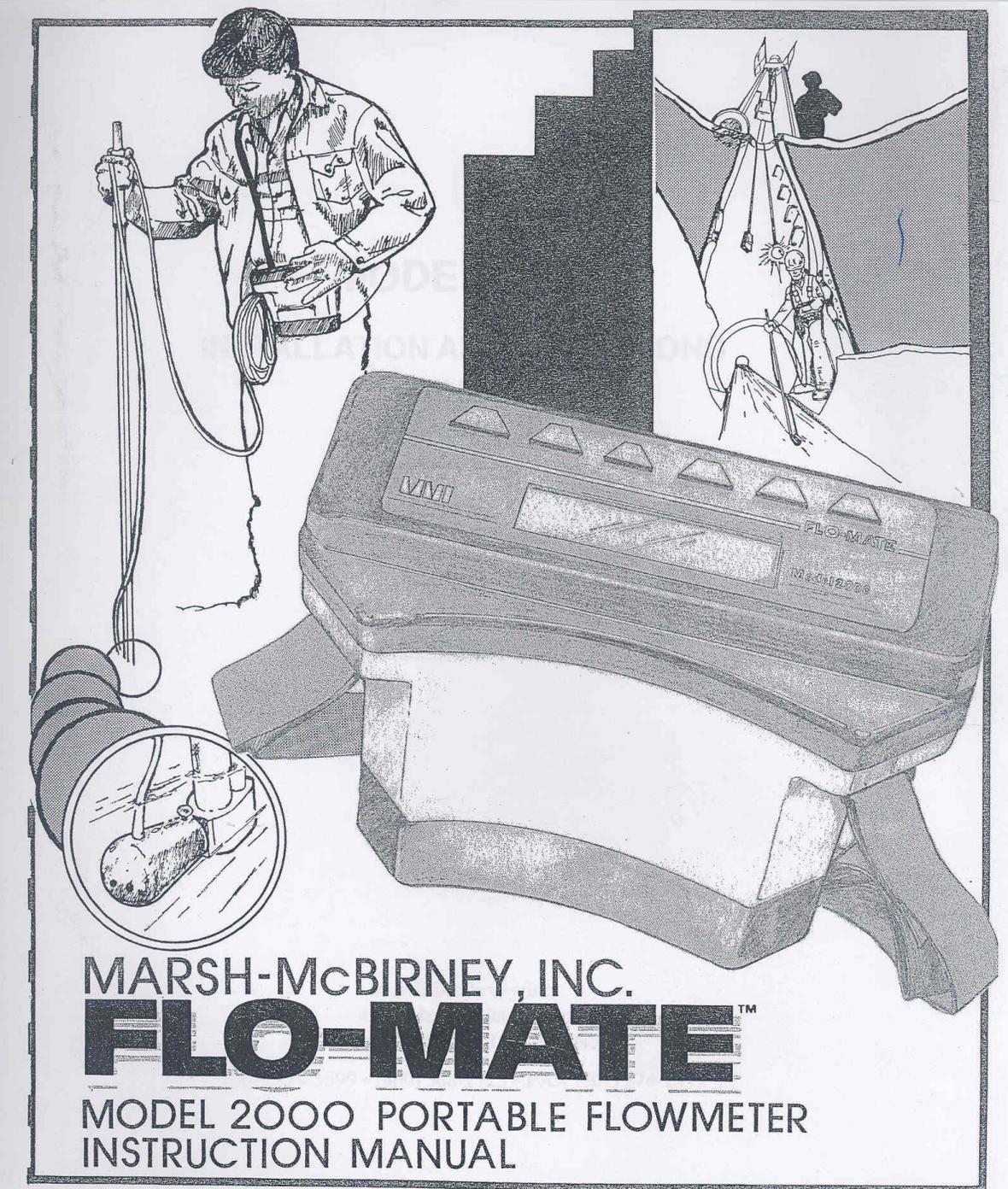


Figure 40. Cover of Model 2000 Marsh-McBirney Flo-Mate Instruction Manual

Theory of Operation (From the Marsh-McBirney Flo-Mate Manual, 1990)

The Flo-Mate measures velocity using the Faraday law of electromagnetic induction. This law states that as a conductor moves through a magnetic field, a voltage is produced. The magnitude of this voltage is directly proportional to the velocity at which the conductor moves through the magnetic field.

When the velocity approaches the sensor from directly in front, then the direction of the flow, the magnetic field, and the sensed voltage are mutually perpendicular to each other. Hence, the voltage output will represent the velocity of the flow at the electrodes.

The sensor is equipped with an electromagnetic coil that produces the magnetic field. A pair of carbon electrodes measure the voltage produced by the velocity of the conductor, which in this case is the flowing liquid. The measured voltage is processed by the electronics and output as a linear measurement of velocity.

Flo-Mate Settings

The use of the function keys are described in Figure 41 below.

Units-You can check the unit to see that it is reading in FT/S by pressing ON/C and OFF keys simultaneously. Press these two keys until FT/S is displayed. You can choose to have the beeper on or off (watch for the little speaker symbol in the lower right-hand corner) by toggling between:

- FT/S no beeper
- M/S no beeper
- FT/S with beeper
- M/S with beeper

Filtering-The fluid dynamics around the sensor electrodes may cause the readings to bounce around. To stabilize the readings, the output to the display is dampened. The display can be dampened by Fixed Point Averaging (FPA) or by time constant filtering (rC). Fixed Point Averaging is an average of velocities over a fixed period of time. Time constant filtering is a software algorithm that mimics an RC analog circuit.

To check the unit and see what filtering method is being used, press the Up and Down arrow keys at the same time until the meter displays FPA (fixed point average). The display will show the letters rC when you first switch to the time constant mode.

Except for the first period, the display is updated at the end of each averaging period. For example, if the FPA is set to 20 seconds, the display is updated once every twenty seconds. The FPA display will have a horizontal time bar under the velocity output. The time bar provides an indication as to the amount of time left until the display is updated.

FLO-MATE™

Model 2000 Key Summary

One Key Function

-  - Turns Unit ON. Clears the display and restarts the meter.
-  - Turns Unit OFF.
-  - Increments Fixed Period Averaging, Time Constant and Memory Location.
-  - Decrements Fixed Period Averaging, Time Constant and Memory Location.
-  - Switches Between Recall and Primary Operating Modes.
-  - Stores Values In Memory.

Two Key Function (Press at same time)

-   - Change Units, Turns Beeper ON/OFF
-   - Toggles Between Fixed Point Averaging and Time Constant.
-   - Clears Memory. Meter must be in the primary operating mode.
-   - Initiates zero adjust sequence. (Zero stability is ± 0.05 ft/sec. See instruction manual for procedure.)



4539 Metropolitan Court • Frederick, MD 21704 USA
Toll Free (800) 368-2723 • (301) 874-5599 • Fax (301) 874-2172

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Figure 41. Key Function descriptions for the Model 2000 Marsh-McBirney Flo-Mate

Time Increment-To set the increment, press the up arrow or down arrow to see if the unit is set to read in 20 second intervals. Note that fixed point averaging is limited to whole seconds in the range of 2-120 seconds.

The Watershed Assessment Branch (WAB) has a standard of collecting velocity measurements in feet per second using Fixed Point Averaging Filtering in 20 second intervals.

Maintenance of Marsh-McBirney Flo-Mate

According to the Marsh-McBirney Flo-Mate manual, the only routine maintenance of the unit is confined to cleaning the sensor, changing the batteries (two alkaline D Cell batteries), and zero-adjusting the instrument. Any instrument calibration or repair must be conducted by the manufacturer.

Cleaning

Non conductive coatings like oil and grease can cause errors or interfere with the velocity readings. This can be remedied by routinely cleaning the sensor head with soap and water. **Do not use any solvents to clean the sensor head!** If the problem persists, clean the electrodes with very fine grit (600) sandpaper. In error readings persist in the field or where you do not have immediate access to soap and water, you may try to use your fingers underwater to rub away oil and grease from the sensor electrodes. Fine clay (smaller than 600 grit) and pencil erasers may also be effective at removing oil and grease.

Zero Check and Adjust

Every month, the meter will need to undergo a zero check and possibly a zero adjust.

Zero Check Procedure

1. Clean the sensor with soap and water as stated above. Make sure the unit is set to operate in FT/S using fixed point averaging (FPA) filtering (***see Flo-Mate Settings above for more information***).
2. Place the sensor in a plastic five-gallon bucket of water. Sensor should be 3 inches away from the sides and bottom of the bucket. This could possibly be achieved by attaching the sensor to the flow rod during the zero check and balancing the flow rod in a hands-free standing position in the bucket. Make sure the water is not moving and wait 10 to 15 minutes. **DO NOT TAKE ANY READINGS WHILE WAITING.**

NOTE: When conducting the Zero Check or Zero Adjust procedure at the WVDEP Headquarters in Charleston, be sure that there is not a passing train during the Zero Check Procedure. It has been observed that passing trains create excessive vibrations in the laboratory end of the building to the extent that it may seriously affect the Zero Check.

3. Using a filter value of 5 seconds (*i.e.*, change the instrument's increment reading from 20 to 5 seconds using the up and down arrows) take a reading from the unit in the still bucket. **BE SURE NOT TO CAUSE ANY EXCESS VIBRATIONS VIA THE SENSOR CORD OR FROM UNNECESSARY MOVEMENT.** Zero Stability is a reading of +/- 0.05 ft/sec. Record the unit

number, the initial zero stability reading for entry into a database later. If the reading is out of this range, the unit will need to be Zero Adjusted (Steps 4-8). If the unit is within the acceptable range, restore the increment reading back to 20.

Zero Adjust Procedure

Note: Each key in the zero adjust sequence must be pressed within 5 seconds of the previous key. If the time between key entries is longer than 5 seconds or if a wrong key is pressed, the unit will display an ERR 3. Turn the unit OFF then back ON and try again.

4. Keep the position of the sensor as described above in step 2. Press STO and RCL keys at the same time. The unit will display a "3".
5. Use the "down" arrow to decrement to zero. The number "32" will be displayed.
6. Unit will decrement itself to zero and turn off. Zero adjust is complete. Return to step 1 above and repeat the zero check to make sure the instrument is within the acceptable range and record the final zero stability reading. If the unit is still out of range, you may attempt the zero adjust sequence again. If repeated attempts to zero adjust fail to correct the unit, it will need to be sent back to the manufacturer for recalibration and possibly repair. If the final zero check is acceptable, restore the increment reading back to 20 and turn the unit off.

Flow Meter Accuracy

The Flow Meter accuracy is +/- 2% of reading + zero stability (which is +/- 0.05 ft/sec). The range is -0.5 to +19.99 ft/sec.

Using the Flo-Mate

1. Insert the sensor peg on the bottom of the sliding flow rod shaft into the hole on the back of the sensor. Position the three electrical sensors horizontal to the plane of the bottom (the foot) of the flow rod. If the sensor is properly positioned, the cord should be coming out of the top of the sensor perfectly parallel to the flow rod shaft. Tighten the thumb screw so that the sensor will not slide off or rotate out of position.
2. AFTER you have set up your flow transect (***See Setting up the Transect below under Stream Flow Measurement Procedures on page 145***) and have the sensor in the water, turn the instrument by pressing the ON/C button.
3. Allow the instrument to run through two cycles. The first 20 second cycle is to allow the turbulence and eddies around the flow rod and sensor to reach equilibrium so that the final reading during the second cycle is as accurate as possible. Since the real time readings are only visible during the first cycle (***as stated above in Flo-***

Mate Settings on page 139), it is recommended that you initialize the second cycle by pressing the ON/C button. In the rare case that the readout during the first cycle stabilizes well before the end of the 20 second cycle, you may initialize the second cycle early by clearing the display. At the end of the second cycle, record the readout. This readout is the average velocity for the second 20 second cycle only. It does not consider the velocity data gathered during the first cycle.

4. Move the sensor to the second increment in the stream, and press the ON/C button to initiate a **new** cycle to begin (you don't want the 20 second cycle reading to include movement while you were moving the wading staff). Repeat Step 2. Repeat steps 2 & 3 until the flow transect is complete.

Notes about error readings

The purpose of displaying errors is to alert the user of possible problems with either the unit or application. Errors can be displayed as messages or numerical codes. There are three error messages and five numerical codes. With the exception of Err 2, error codes freeze the display. Turn the unit OFF then back ON to clear the display. If after corrective action the error still exists, call the factory. Descriptions of the meanings of each error message are as follows:

Low Bat – Indicates low batteries. Replace the batteries

Noise – Indicates excessive electrical noise is present in the velocity that will interfere with normal operation. This will cause the display to blank out.

Note: The noise flag usually comes on for few a seconds after the sensor is submerged even though there is no noise present. This is normal.

Con Lost – Indicates that either the sensor electrodes are out of the water or they have become coated with oil or grease. After 5 minutes, the unit will turn itself OFF. If the electrodes are coated, clean them (see *Cleaning* above).

Error#1 – There is a problem with sensor drive circuit. Check sensor disconnect.

Error#2 – Memory full error. Memory must be cleared before another reading can be stored.

Error#3 – Incorrect zero-adjust-start sequence. Reinitiate zero-adjust-start sequence.

Error#4 – Zero offset is greater than the zero adjust range. Repeat the zero-adjust procedure. If the error is still displayed, the unit needs servicing.

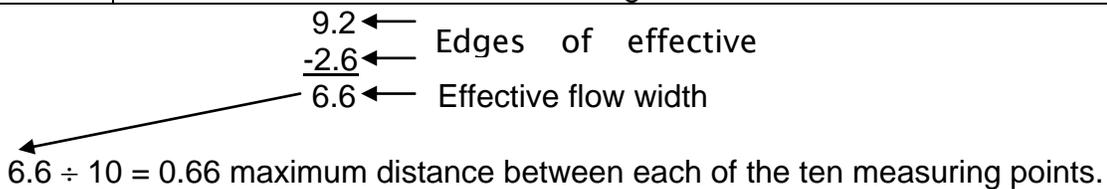
Error#5 – Conductivity lost or noise detected during zero adjust. This is usually caused by the sensor being out of the water.

Note: The sensor on the flow meter has an operating temperature of 0°C to 72°C (32°F to 160°F). The electronics on the flow meter have an operating temperature of 0°C to 50°C (32°F to 122°F).

Part 2. Stream Flow Measurement Procedures

Table 8. Example of Flow Measurement Form: Recording field data.

STREAM DISCHARGE MEASUREMENT (Calculated in cubic feet per second – cfs)					
Measurer	<i>Doug Wood</i>	Meter ID	2	Time	12 noon
Location	Distance	Depth	Velocity	Discharge	cfs
Bank	1.3				
EEF	2.6	This is the Edge of Effective Flow			
1	2.93	0.64			
2	3.59	0.90			
3	4.25	0.93			
4	4.91	0.97			
5	5.57	1.01			
6	6.23	1.12			
7	6.89	1.06			
8	7.55	0.92			
9	8.21	0.88			
10	8.87	0.63			
11	9.2	0.60			
EEF	9.9	This is the Edge of Effective Flow			
Bank	10.5				
Notes:	Some turbulence from rocky substrate. Slightly skewed flow. Drizzling rain.				



Note: ALL MEASUREMENTS TAKEN IN INCHES MUST BE CONVERTED TO FEET AND TENTHS/HUNDREDTHS IN ORDER TO GIVE A WIDTH MEASUREMENT THAT CAN BE USED IN CALCULATING FLOW/DISCHARGE IN UNITS OF CUBIC FEET PER SECOND (cfs).

Setting up the Transect

1. Select a stream reach having the following characteristics:
 - a. A straight stretch of water with the horizontal velocity vectors running parallel to the stream bank
 - b. A stable, even streambed without large rocks, weeds and protruding obstructions that create turbulence.
 - c. A level streambed configuration to reduce variation in the vertical components of velocity.

All of these conditions are seldom satisfied. Nevertheless, select the best possible reach using these criteria.

2. Next, select a flow transect. An ideal transect:
 - a. Is perpendicular to the direction of flow (velocity vectors). It is often very hard to find an area of stream where 100% of the flow is perpendicular to the flow transect. If there is no better place to take the velocity readings, then the number of varying velocity vectors on a flow transect should be kept to a minimum.
 - b. Has uniform bed and stream banks
 - c. Has a minimum velocity of 0.05 feet/second. Avoid transects with eddies or areas of “dead” water. **(However, you should include positive number readings of less than 0.05 feet/second on the flow sheet should you encounter them.)**
 - d. Adequate depth for the meter to function. Typically, this means the entire velocity probe bulb should be immersed. **Please note if readings were taken with part of the bulb exposed to air. If the bulb was removed from the flow rod and placed on the substrate, please note this as well.**

Note: You may alter the channel to help meet these requirements at the selected site before you begin making any measurements, but NEVER AFTER measurement has begun.

3. Determine the width of the stream by placing a tape measure perpendicular to the stream flow.
4. Determine the width of “effective flow”. The effective flow is the segment of the transect having measurable downstream velocity and exclusive of “dead” areas or reverse flows (eddies) beside the stream banks. Do not exclude similar anomalous flow areas that do not touch the banks from the width measurement (bank to bank). For simplicity, utilize this effective flow width in establishing endpoints for measurement of velocity and depth (**see Table 8 above**).

5. Determine spacing of velocity measurements. There is no set rule about how to space the measurements other than there is a required minimum number of measurements depending on the width of the effective flow (see arrow bullets below this paragraph). **Velocity measurements should be spaced to document and define areas of turbulence, extreme changes in velocity, and sudden changes in depth. For example, if there is a large obstacle to the flow like an unmovable boulder directly in, in front of, or behind the flow transect, a few extra measurements should be taken on each side of the boulder and spaced closer than the average increment. The velocity measurements can also be spaced farther apart in areas where the velocity and depth are more uniform.**
 - In streams with effective flow width greater than 3 feet, take no fewer than ten nearly even-spaced measurements within the effective flow transect. For example, if the effective flow is 3.5 feet wide, the minimum number of ten measurements could be taken every 4.2 inches (this is 10% of the effective flow width, 42 inches).
 - If the effective flow width is less than 3 feet, take as many measurements as possible using an increment no smaller than 0.3 ft using best professional judgment.
 - If the effective flow is >10 feet, a minimum of 20 measurements should be obtained.
6. Record the following information on the **APPENDIX #1 - Stream Discharge (Flow form (see Figure 27 above on page 79))**:
 - a. Record the flow measurer.
 - b. The time of the flow measurement.
 - c. The assigned number of the flow meter used.
 - d. Any conditions that might affect the flow measurement (*i.e.*, wind, rain, skewed bottom configuration, ice and leaf packs in the water, necessity of removing the probe bulb from the rod due to extremely shallow water depth).

Taking Flow Measurements

7. Begin Flow measurement (**See Figure 39 above on page 136**):
 - a. For simplicity, establish the bank as the initial point. Then record the distance (L_0) from the initial point to the edge of effective flow. Record the depth at the edge of effective flow (d_0).
 - b. Record the distance (L_1) from the edge of effective flow to the first velocity measuring point along the tape. (This point is called a “vertical”). This first vertical should be established at a distance very close to the edge of effective flow (about 0.3-0.5 feet). Record water depth (d_1) at this vertical.

- c. If the depth is less than 2 feet, use the one-point 0.6-depth method for measuring velocity: Adjust the rod so that the sensor is at the depth that is six-tenths below the water surface (indicated by “1” in **Figure 27 above on page 79**) by lining up the rod’s sliding “foot” with the tenth scale vernier on the top of the flow rod (e.g., if total depth is 0.9 foot, then line up the “0” line on the rod’s sliding foot scale with “9” on the tenth vernier. If depth is 1.2 feet, then line up the “1” sliding foot scale line with the “2” vernier line). If the depth is greater than 2 feet, two readings are taken: 0.2 and 0.8 from the surface.
- To set the sensor at 0.2 of the depth, multiply the total depth by two and repeat the above procedure. For a depth of 2.7 feet, this would be 5.4 feet. Line up the 5 on the foot scale with 4 on the tenth scale.
 - To set the sensor at 0.8 of the depth, divide the total depth by two and repeat the above procedure. For a depth of 2.7 feet, this would be 1.35 feet. Line the 1 on the foot scale with 0.35 on the tenth scale.

Note: To obtain a discharge figure for entry in the computer program for a two-reading measurement, calculate the average of the two velocity readings, and use this average velocity for calculating the discharge in the two-reading transect increment.

- d. Place the sensor at the proper depth and allow it to adjust to the velocity before starting the observation. The following precautions should be taken:
- Hold the rod perfectly straight up with the sensor pointing upstream into the velocity vector (parallel). The bow wave produced by the wire at the top of the sensor will be symmetrical if the sensor is pointing directly into the flow. A ribbon attached to the bottom of the flow rod also helps visualize the flow direction.
- Note:* The manufacturer says the sensor shape produces a cosine response that greatly reduces errors due to sensor positioning. For example, if the front of the sensor is pointed away from the flow at a 10° angle, the cosine of 10° is 0.98480. This is only 1.5% lower than the actual velocity. What this means is that even though you may not have the flow reading positioned 100% parallel to the flow vector, a few degrees off of center will yield pretty accurate results. Nevertheless, you should still try to position the sensor as close to parallel to the flow vector as possible! Experience shows the manufacturer’s rhetoric is just that. In the real world, slight angles away from parallel with the velocity vector, produce noticeably different velocity readings.
- Stand downstream from the meter and at a distance so that you do not create turbulence that will impact the reading. In very small streams, attempt to straddle the wetted area to decrease your feet’s contributions to altering the flow.

- e. Allow the Flo-Mate to go through two complete cycles (40 seconds total) as described in ***Using the Flo-Mate above on page 142.***
 - f. Record the second readout on the “velocity” column on the form.
8. Repeat Step 7 at each vertical, recording the distance, depth, and velocity. Be sure to record the distance to and depth of the far bank and vertical point of effective flow.

Calculating Flow Using a Spreadsheet

1. Open Excel, and then open the file in Q:\WATER RESOURCES\WAB\TOOLS\Flow Template.xls.
2. At the bottom of the spreadsheet select the tab for the number of actual flow readings obtained. If there is no tab for the number of measurements you have taken, you will need to insert a new worksheet, copy contents of another worksheet into the new worksheet, and add or delete rows as needed.
3. Type in the left and right edge-of-effective-flow values in the “no flow” rows of the “Distance” column.
4. Enter the distance, depth, and velocity in the appropriate columns.
5. The flow or discharge in CFS is automatically calculated in the lower right-hand corner of the spreadsheet.

Section B. Measuring Flow Using a Bucket and Stop Watch

On some rare occasions, it may be possible or more practical to measure flow using a bucket of known volume and a stop watch. Such instances include measuring flows coming out of a pipe where there is adequate room to place the bucket underneath the pipe. The procedure to measure a flow in this manner is to measure the seconds it takes to fill up the bucket. It is recommended that you measure this at least three times and take the average time as the final reading. Converting this measurement into cubic feet per second (CFS) units may require some research into conversion units (e.g., gallons or liters into cubic feet). However, the flow template sheet mentioned above (located at Q:\WATER RESOURCES\WAB\Flow Template.xls) contains a worksheet already calibrated to convert measurements using gallons per second into cubic feet per second. Simply enter the seconds it took the fill up the bucket, the volume of the bucket in gallons and the resultant CFS will be calculated at the end of the row. Document on the field sheet the flow method and the individual and final average CFS.

Section C. Measuring Flow Using a USGS Gauging Station

In some instances, a sampling station on a larger stream may coincide or be very near a USGS Gauging Station. If this is the case, then flow readings could be read from the USGS gage. USGS maintains a website to access current and historical stream

discharge and stream stage data from the gages. The web addresses for West Virginia daily stream gage data are:

<http://waterdata.usgs.gov/wv/nwis/current?type=dailystagedischarge>

<http://wv.usgs.gov/>

<http://waterwatch.usgs.gov/?m=real&r=wv>

See Figure 77 and Figure 78 in Chapter X. Section A. Part 4. Measuring Stream Flow starting on page 230 for examples of USGS website data displays.

Once you have accessed a specific gage, you will need to use the real time and table options to view hourly gage data. Record the USGS gage number, discharge and/or stage readings, for the date and time sampled, onto the analysis request form. Hourly data are available for up to 60 days, from the date a site is visited. Daily averages are available up to two years.

Flow Measurement Quality Assurance/Quality Control

Before use, each Flo-mate velocity-meter should be examined for wear and fouling, and adjustments should be made as required.

Zero check and adjust logbooks are maintained for each instrument and entered into a database. Any instrument failing to meet zero check requirements is zero adjusted or shipped to the manufacturer for diagnosis and repair. Flow meters are checked monthly and may be zero checked and adjusted in the field if necessary.

Each flow meter has an identification number, which is recorded on the habitat assessment sheet each time it is used. If any instrument fails a zero check, readings taken prior to the failed zero check will be examined for reliability and accuracy. Documentation of the instrument used at each site will help to keep data loss to a minimum. All repair logs to flow meters are documented and maintained by the manufacturer and noted in a repair log.

Once a year, all field participants in the WAB attend mandatory training sessions in March-April prior to the initiation of the major sampling season. The purpose of these sessions is to ensure that all field personnel are familiar with sampling protocols and calibrated to sampling standards. A hands-on session concerning the measurement and collection of flow data is included. Any persons unable to attend the annual training session will be instructed and evaluated on the job in the following month by one of the WAB training instructors. Individual training will occur simultaneously on the same stream so the results can be compared to the group average. Readings that deviate exceptionally from the norm will be examined for errors. In the field, individuals who are more experienced in determining flows will be teamed up with the less experienced to assure reinforcement of training and accurate results before they are allowed to measure flows solo. This document is also provided to all program personnel for review and use in the field.